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Jerry M. Sollinger, Carolyn Wong

ROOT CAUSE ANALYSES OF NUNN-MCCURDY BREACHES

VOLUME 2

Excalibur Artillery Projectile
and the
Navy Enterprise Resource
Planning Program,

with an Approach to
Analyzing Program
Complexity and Risk

Prepared for the Office of the Secretary of Defense

RAND NATIONAL DEFENSE RESEARCH INSTITUTE

The research described in this report was prepared for the Office of the Secretary of Defense (OSD). The research was conducted within the RAND National Defense Research Institute, a federally funded research and development center sponsored by OSD, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community under Contract W74V8H-06-C-0002.

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Preface

As a result of continuing concern with large cost overruns in a broad range of major defense programs, Congress enacted new statutory provisions extending the ambit of the existing Nunn-McCurdy Act. In accordance with the revised Nunn-McCurdy law, the Performance Assessments and Root Cause Analysis (PARCA) office must provide its root cause explanation as part of a 60-day program review triggered when the breach is reported by the applicable military department secretary.

In March 2010, the newly created PARCA office within the Office of the Secretary of Defense (OSD), in view of staffing limitations, elected to rely on federally funded research and development center (FFRDC) support to help discharge its new responsibilities. It engaged the RAND Corporation to study the root causes of Nunn-McCurdy breaches or other large cost increases in six major defense acquisition programs: the Wideband Global Satellite, the Longbow Apache, the DDG-1000, the Joint Strike Fighter, the Excalibur, and the Navy Enterprise Resource Planning (ERP).

This monograph contains the analysis performed by RAND on the last two of these six root cause analyses: Excalibur and the Navy ERP. Analyses of the other four programs appear in a companion report.[1] In addition, this report develops some exploratory concepts of program risk and complexity as factors in the management of program acquisition. This report should interest anyone concerned with the acquisition and management of defense systems.

This research was sponsored by OSD PARCA and conducted within the Acquisition and Technology Policy Center of the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense Intelligence Community.

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1 Irv Blickstein et al., *Root Cause Analyses of Nunn-McCurdy Breaches, Volume 1:* Zumwalt-*Class Destroyer, Joint Strike Fighter, Longbow Apache, and Wideband Global Satellite,* Santa Monica, Calif.: RAND Corporation, MG-1171/1-OSD, 2011.

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Summary

Background

As a result of continuing program cost growth and observations by the Government Accountability Office (GAO) placing defense acquisition on the high-risk target list, Congress became particularly concerned about the execution of major defense acquisition programs. This concern and the reality of shrinking defense budgets led Congress to enact laws that would increase the focus of senior policymakers on oversight of major defense acquisition programs (MDAPs) and other large costly programs.[2] The Weapon Systems Acquisition Reform Act (WSARA) of 2009[3] established a number of requirements that affected the operation of the Defense Acquisition System and the duties of the key officials who support it, including the requirement to establish a new organization in the Office of the Secretary of Defense (OSD) with the mandate to conduct and oversee performance assessments and root cause analysis (PARCA) for MDAPs.

In March 2010, the director of the PARCA office determined that he needed support to execute his statutory responsibilities and turned to federally funded research and development centers (FFRDCs) and academia to provide that support for the research and analysis of program execution status. RAND was one FFRDC engaged to perform research and analysis and provide recommendations and was originally assigned responsibility for four programs.[4] After completing that initial effort, RAND was assigned two additional programs for research and analysis: Excalibur and the Navy Enterprise Resource Program (ERP).

Purpose

This report does two things. First, it analyzes the root cause of cost overruns in two programs: the Army Excalibur artillery round and the Navy ERP. The Excalibur proj-

2 Ike Skelton Defense Authorization Act for Fiscal Year 2011, December 20, 2010.

3 Public Law 111-23, Weapon Systems Acquisition Reform Act of 2009, May 22, 2009.

4 Blickstein et al., 2011.

ect incurred a Nunn-McCurdy breach. The ERP did not, but the cost growth was so great that the Department of Defense (DoD) requested a root cause analysis.

Second, it presents what can be described as an exercise to help identify the most critical features of a program. Critical program components are those that carry the most risk of overall program failure. The exercise is designed to identify the important program features that decisionmakers would want to concentrate on when inquiring about a program as it develops over time. The report then uses the results of the exercise to flag the most critical features of the weapon system, using Excalibur as an example. The exercise and the illustration help to frame one approach for considering program failure risk in programs that have not yet breached.

Observations on the Conduct of Root Cause Analyses

Each acquisition program is unique, and each root cause analysis (RCA) is unique. However, RAND's experience in conducting six root cause analyses indicates that a set of core activities is instrumental to a successful effort. These activities define a generic root cause methodology whose key components include the following:

- Gather and review readily available data.
- Develop a hypothesis.
- Set up long-lead-time activities.
- Document the unit cost threshold breach.
- Construct a time line of relevant cost growth events in the program history.
- Verify the cost data and quantify cost growth.
- Create and analyze the program cost profiles pinpointing occurrences of cost growth.
- Match the time line events with changes in the cost profiles and derive root causes of cost growth.
- Reconcile any remaining issues.
- Attribute unit cost growth to root causes.

Successful execution of this set of activities should enable the research team to create the primary deliverables and postulates for a root cause analysis: a summary narrative that includes clearly stated root causes of cost growth supported by a formal documentation of the cost threshold breach, a summary time line of program events leading to the Nunn-McCurdy breach, funding profiles, a completed PARCA-office-generated root cause matrix, and a breakdown of the amount of cost growth attributable to each root cause; a briefing that corresponds to the narrative; and a full root cause report.

In addition to developing deliverables and postulates, the RCA process is designed to improve the research focus iteratively. At each stage of the RCA, information is drawn from and contributed to the program archive. The RCA analytic team can use this insight not only to improve the interim products that result from successive stages of the RCA but also to advance the original hypothesis that guides the research. This process of regularly refining the guiding hypothesis with the insight gained during the production of key deliverables and postulates enables the research team to quickly identify the root causes of a program's failure.

Findings of Root Cause Analyses

Excalibur

RAND's root cause analysis identified one primary driver and four contributing factors to Excalibur's Nunn-McCurdy cost breach. The most significant source of cost increase was the *change in procurement quantities*: a 79 percent reduction in the number of Excalibur rounds ordered. The root causes of this quantity reduction were changes in requirements combined with affordability considerations. Specifically, the manner in which artillery was being used and the precision of the Excalibur round meant that fewer would be needed.

An Army review of precision-guided munitions capability placed the required quantity of Excalibur munitions in the context of the other guided munitions in the Army's arsenal, leading to a decision to reduce the Army's procurement objective for Excalibur. The quantity reduction, resulting from changes in perceived requirements, was so large that Nunn-McCurdy unit cost breaches would have occurred even in the absence of any other factor.

Another four factors contributed to some program cost growth before the decision was made to reduce procurement quantity. *Inaccurate cost estimates* contributed to some cost growth. Both the original May 1997 cost estimates and the initial Selected Acquisition Report (SAR) estimates were too low to reflect the technological improvement represented by Excalibur, making an eventual cost overrun more likely. Additional drivers of the cost growth before the breach include a *concept and technological change* that occurred between the original solicitation and the contract award in January 1998, as well as some *minor technical issues* that were identified between 2002 and 2010. Finally, Excalibur unit cost growth was driven by the validated and *urgent operational need for Operation Enduring Freedom/Operation Iraqi Freedom* (OEF/OIF), which caused production to be accelerated and more Increment Ia rounds produced than initially planned.

Excalibur was unaffected by other potential root causes. For example, it lived up to its performance expectations, was not affected by poor government or contractor performance, and had sufficient and fairly stable sources of funding.

Navy Enterprise Resource Planning

Although the Navy ERP program technically breached the Nunn-McCurdy cost growth limits and was implemented behind schedule, the program can be considered a qualified success. The majority of cost growth and schedule delays occurred in 2004 and 2005. Since the 2006 re-baseline, costs have stabilized and production delays have been limited.

Part of the root cause of the 2004 cost overrun was a somewhat *optimistic baseline for cost and schedule*. The greater problem was the *unexpected change in business practices* caused by the Navy's decision, after the Base Realignment and Closure (BRAC) process, to move maintenance from an intermediate-level construct to a regional one. The latter led to the major schedule slippage in 2005 and forced the ERP program to jettison its extension to maintenance activities.

The ERP program was re-baselined in 2006 at $400 million higher. The increase arose from a redesign of the system, a change in business practices, and an improvement in estimates. Since 2006, ERP costs have stabilized and the program has been successfully implemented at three System Commands (SYSCOMs). Minor additional slippage in schedule has occurred primarily as a result of timing issues rather than program delays or failures.

The Navy ERP can be considered a qualified success. Although initial cost growth and schedule slippage were significant, they were not explosive, and the ERP program was never in real danger. Several factors may have contributed to relative program success, including the use of pilot projects, cost-plus contracting, the decision to minimize the customization of the SAP solution, interactive governance and high leadership interest, and a willingness to rely on the managerial and technical expertise of civilian cadres.

Program Complexity

One conclusion drawn from the analysis of the six programs that had Nunn-McCurdy breaches is that key decisionmakers lacked adequate visibility into the programs. After analyzing the programs that breached, it became clear that indications existed that a breach was possible (or even likely), but they were buried in the program documentation. This opaqueness occurs because key details can be hidden in the voluminous documents a program produces or can appear only as elliptical references in program reports. Thinking about how to mitigate this problem, RAND researchers determined that a well-constructed framework could help decisionmakers identify areas where a program might have greater risk for problems (and thus a potential Nunn-McCurdy breach) so that they could direct more management attention to those areas.

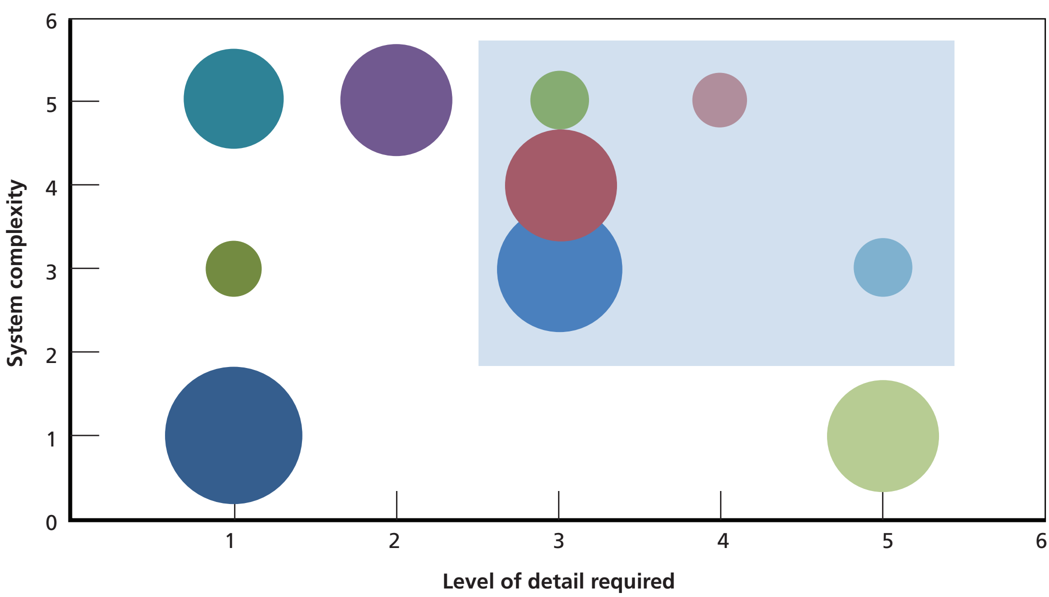
The research team proposed that decisionmakers use a "selective screening of critical components" process to identify the features of most risk to a program. The process

relates measures of merit drawn from a variety of *Jane's* publications used to describe programs to the complexity and level of data detail available for specific program features. A measure of merit is broadly a set of technical components that contribute to a measurable process. An example of a measure of merit pertains to the turboshafts of the Apache helicopter and is described as the "maximum continuous drive" for the platform. Other helicopters and other systems also use the maximum continuous drive measure of merit. The measure includes specific technical components as well as systems of components used to generate a particular level of performance, in this case maximum continuous drive. Researchers developed a graphical display technique to help identify likely areas of risk.

The most important measures of merit for program personnel to consider are the ones that are both highly complex and the least visible. The display in Figure S.1 shows measures of merit that have been coded for level of complexity and detail required (e.g., a more complex system requires more detail).

With this tool, the decisionmaker or analyst can evaluate the frequency of components at various regions of the resultant "complexity-detail matrix" to get a better view of the measures of merit that contain the program features with the most potential risk. Construction of this matrix is an important aspect of the selective screening process. For the Longbow Apache, the shaded blue square highlights the system components that are closer to the upper right corner of the display, i.e., those that are the most complex yet the least visible. These are the ones that warrant greater attention

Figure S.1
Longbow Apache Nominal Example



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from the program managers. Use of common metrics allows programs to be compared across systems.

Program Risk

The project team also developed a methodology to identify technical risk in a program's most critical components early enough to allow project managers to take action to avoid a Nunn-McCurdy breach. The risk experiment explored the Excalibur artillery round. First, researchers went through the process described above to identify the key components, i.e., those on the critical path of program success. For Excalibur, these turned out to be the global positioning system (GPS) and the inertial measurement unit (IMU).

Having identified the critical components of the Excalibur program, the team then turned to Defense Contract Management Agency (DCMA) parts management program (PMP) and Defense Acquisition Executive Summary (DAES) risk assessments to ascertain if either DCMA or DAES presaged the problems. The DCMA reports were issued monthly. Those RAND received covered only 31 months of a 13-year program, but they contained enough data to detect patterns. The DCMA reports use a stoplight system to highlight risk for technical components. The DAES risk assessments are periodic summaries provided to the Defense Acquisition Executive.

Review of the DCMA reports showed that the summary-level judgments assessed moderate program risk, but delving into the data at the subcategory level uncovered a different picture. Arraying the lower-level DCMA component ratings against the DAES summary ratings showed that although the DAES ratings never changed from moderate risk, the DCMA component ratings showed numerous instances when risk ratings for the IMU were rated as high. Yet the fact that a component essential to the success of the program was seen as high risk because of cracks in components revealed during testing over several rating periods was not brought to the attention of senior decisionmakers. The GPS receiver also experienced problems, with communications and software in this instance, which caused several flight failures. Better use of available data could have signaled potential problems to senior program personnel.

Acknowledgments

RAND's Navy ERP analysis team extends its sincere appreciation to Beverly Veit for connecting the team with numerous individuals involved with the Navy ERP program; without her support, our work would have suffered greatly. We thank former and current members of the Navy ERP program office, including Ron Rosenthal, Jennifer Carter, Valerie Carpenter, and Susan Keen, for their willingness to participate in lengthy and extraordinarily helpful discussions about the program. We thank John McNair and Dennis Taitano for their insights regarding the creation and expectations of the Navy ERP. Rear Admiral (Ret.) Robert Cowley provided essential information regarding the history of the Navy ERP governance structure. Although the list of individuals who offered substantive time to inform our work is long, we would like to acknowledge the teams in Naval Air Systems Command; Naval Supply Systems Command; Deputy Assistant Secretary of the Navy, Command, Control, Computers, and Intelligence; and the Business Transformation Office for their valuable contributions.

For Excalibur, James Wiltz at Acquisition, Technology, and Logistics (AT&L)/Principal Support Authority and the program office personnel provided valuable insight and information in support of the analysis of this complex system.

We want to acknowledge our interaction with Director Gary Bliss and David Nicholls of the PARCA office.

We also enjoyed, and benefited from, informal collaboration with colleagues at the Institute for Defense Analyses. We also received helpful support from RAND colleagues familiar with the programs we studied.

We also express our appreciation for the good work done by our two reviewers, Jack Graser and Mike Hammes. Their thorough and thoughtful reviews made this a better report.

We wish to thank Jennifer Miller and Alex Chinh, who provided administrative support and technical support for the project.

Abbreviations

AAE	Army Acquisition Executive
ACAT	Acquisition Category
ADM	Acquisition Decision Memorandum
AIS	Atlantic Inertial Systems
APB	acquisition program baseline
APUC	average procurement unit cost
AT&L	Acquisition, Technology, and Logistics
BRAC	Base Realignment and Closure
BY	base year
CAR	corrective action request
DAES	Defense Acquisition Executive Summary
DAMIR	Defense Acquisition Management Information Retrieval
DCMA	Defense Contract Management Agency
DoD	Department of Defense
ERP	Enterprise Resource Planning
FAA	Federal Aviation Administration
FFRDC	federally funded research and development center
FY	fiscal year
GAO	Government Accountability Office
GPS	global positioning system
HR	House Report

IMU	inertial measurement unit
IOC	initial operational capability
IOT&E	initial operational test and evaluation
kW	kilowatt
MAIS	Major Automatic Information System
MDAP	major defense acquisition program
MS B	Milestone B
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NAVSUP	Naval Supply Systems Command
NLOS	non–line-of-sight
NLOS-LS	non–line-of-sight Launch Systems
O&M	operations and maintenance
O&S	operations and support
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
OUSD	Office of the Under Secretary of Defense
PARCA	performance assessments and root cause analysis
PAUC	program acquisition unit cost
PDR	Program Deviation Report
PEO-AMMO	Program Executive Officer for Ammunition
PMP	parts management program
POM	Program Objectives Memorandum
RCA	root cause analysis
RDT&E	research, development, test, and evaluation

RDW	Request for Deviation/Waiver
SAE	service acquisition executive
SAR	Selected Acquisition Report
SPAWAR	Space and Naval Warfare Systems Command
SSSFM	Spin Stabilized Sensor Fused Munition
SYSCOM	System Command
USC	U.S. Code
WGS	Wideband Global Satellite
WSARA	Weapon Systems Acquisition Reform Act

CHAPTER ONE

Introduction

Background

The U.S. Congress continues to express concern with cost increases in major defense acquisition programs (MDAPs). This concern and shrinking defense budgets have led Congress to effect statutory provisions that would focus more attention of senior policymakers on oversight of MDAPs[1] and other large costly programs.[2] The Weapon Systems Acquisition Reform Act (WSARA) of 2009[3] established a number of requirements that affected the operation of the Defense Acquisition System and the duties of the key officials who support it, including the requirement to establish a new organization in the Office of the Secretary of Defense (OSD) with the mandate to conduct and oversee performance assessments and root cause analysis (PARCA) for MDAPs.[4] The act assigned the PARCA organization five primary responsibilities:

1. Carry out performance assessments of MDAPs.
2. Perform root cause analysis (RCA) of MDAPs whose cost growth exceeds the threshold as detailed in the Nunn-McCurdy Act.
3. Issue policies, procedures, and guidance governing the conduct of performance assessments and root cause analyses.
4. Evaluate the utility of performance metrics used to measure the cost, schedule, and performance of MDAPs.

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1 U.S. House of Representatives, House Report (HR) 111-124 on S. 454, "Weapon Systems Acquisition Reform Act of 2009," May 20, 2009; U.S. House of Representatives, Committee on Armed Services, House Report 111-101 on HR 2101, "Weapons Acquisition System Reform Through Enhancing Technical Knowledge and Oversight Act of 2009," May 12, 2009.

2 Ike Skelton Defense Authorization Act for Fiscal Year 2011, December 20, 2010.

3 Public Law 111-23, Weapon Systems Acquisition Reform Act of 2009, May 22, 2009.

4 Ashton B. Carter, Under Secretary of Defense, Acquisition, Technology, and Logistics (OUSD [AT&L]), "Directive-Type Memorandum (DTM) 09-027—Implementation of the Weapon Systems Acquisition Reform Act of 2009," December 4, 2009; Public Law 111-23, § 103.

5. Advise acquisition officials on performance issues that may arise regarding an MDAP.[5]

Purpose

This report, the second of a continuing series of reports that capture RAND efforts to support the PARCA office, has two purposes.[6] The first is to provide additional root cause analyses of two programs, the Army Excalibur and the Navy Enterprise Resource Planning (ERP) program. These two programs, although costly, are not major platforms, but the analysis required differing approaches. As a result, researchers had differing benchmarks and metrics to contend with.

The second purpose is to present an approach to help identify the most critical technical features of a program. Critical program components are the ones that pose the greatest risk of overall program failure. The approach is designed to identify the important program features that decisionmakers would want to monitor closely as the program progresses. The report uses an exercise to flag the most critical features of the weapon system, using Excalibur as an example. The method and the illustration help to frame one approach for considering program failure risk in structuring and reviewing programs.

The Root Cause Analysis Environment

Federal law shapes the environment in which RCAs are conducted, especially the time available to do them. In general, the notification of an overrun and an explanation of its causes must occur quickly. The period of time available for the RCA, while short in any case, can be either 45 or 60 days. 10 U.S. Code (USC) § 2433(c) directs the program manager of a major defense acquisition program to submit a unit cost report to the appropriate service acquisition executive (SAE) when he or she first determines that there is reasonable cause to believe that the program has incurred a unit cost threshold breach.[7] If the SAE makes the same determination and the military department secretary concurs, the secretary of the department concerned must notify Congress in writing within 45 days of the program manager's initial report.[8]

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5 Public Law 111-23, § 103.

6 See Blickstein et al., 2011.

7 For a detailed discussion of unit cost threshold breaches, see Blickstein et al., 2011.

8 If the program manager's initial report is in a quarterly Selected Acquisition Report (SAR), then the service secretary is required to notify Congress in writing within 45 days after the end of the quarter. See 10 USC § 2433.

WSARA requires that a weapon system acquisition program undergo an RCA when it incurs unit cost growth that exceeds thresholds set by federal law.[9] WSARA directs the Secretary of Defense to initiate an RCA after consultation with the Joint Requirements Oversight Council.[10] § 103 of WSARA assigns responsibility for carrying out an RCA to the senior official designated by the Secretary of Defense for this purpose—that official is the director of the PARCA office. 10 USC § 2433(a) states that notification to Congress of program recertification by the Secretary of Defense is required before the end of the 60-day period that begins on the day after the next SAR is required by 10 USC § 2432(f).

The legal reporting requirements described above show that the exact number of days within which an RCA must be completed can vary. The variance stems from two facts. The 45-day period between the program manager's report and the military department secretary's notification to Congress of a critical unit cost breach (a Nunn-McCurdy breach) starts the day after the program manager initially reports the breach to the SAE.[11] In contrast, the 60-day period within which the Secretary of Defense must submit a program recertification decision to Congress starts on the day after the due date of the first SAR that reports the Nunn-McCurdy breach. Figures 1.1 and 1.2 depict the process and time lines.

In either case, not much time is available for the analysis, which has implications for how many data can be collected and from where. To illustrate how short a time period this might be, the Secretary of the Air Force notified Congress of the Wideband Global Satellite (WGS) program Nunn-McCurdy breach on March 8, 2010. RAND received word of tasking about ten days later, and the PARCA office request for initial RCA results came during the second week of April. Hence, the WGS RCA team had approximately 30 calendar days to identify root causes of this breach.

The discussion above shows that the primary consideration that RCA teams should keep in mind while designing a plan to conduct an RCA is that it must be completed within a short period of time. As we will see in the following discussion on approaches to investigating common characteristics where an RCA methodology is presented, this short time period dictates that many tasks occur simultaneously and that a collaborative team effort is required to integrate the specific findings into a cohesive narrative of events at the root of a Nunn-McCurdy breach. Since analysts must base their findings on reliable data, timely access to relevant program information is critical to the success of an RCA. The data aspect is discussed below and in the data sources section that follows. Finally, the RCA findings accompany the Secretary of

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9 See 10 USC § 2432 and 10 USC § 2433. Although the program manager, SAE, and military department secretary must notify Congress of significant and critical unit cost breaches, the WSARA requires RCAs only for programs that have incurred critical unit cost breaches.

10 See 10 USC § 2433(a) of as specified in § 206 of Public Law 111-23.

11 See 10 USC § 2433.

Figure 1.1
Legally Mandated Activities Related to RCAs

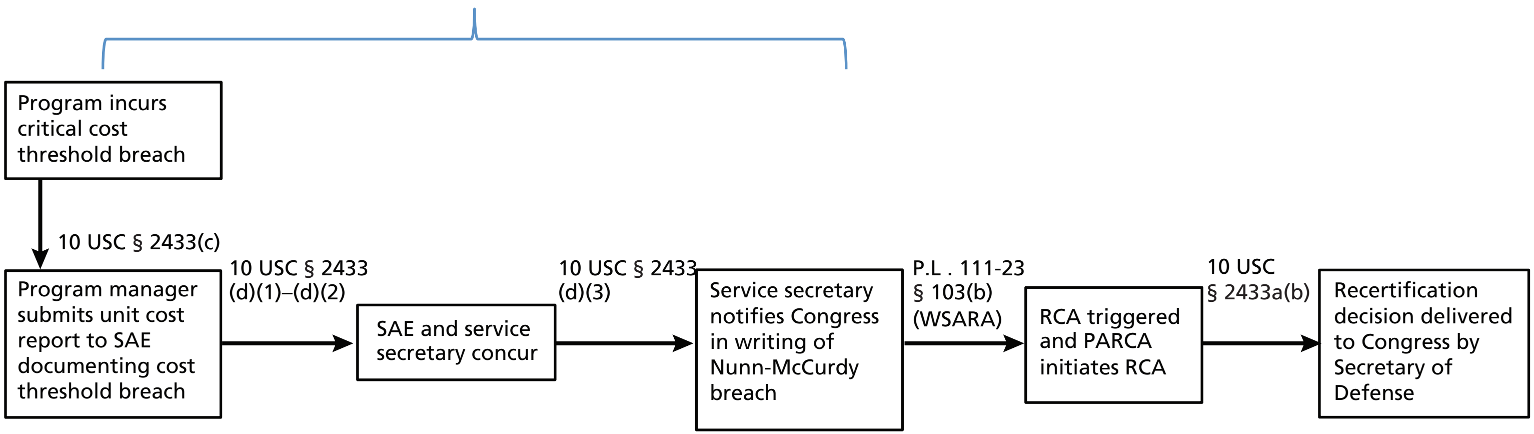

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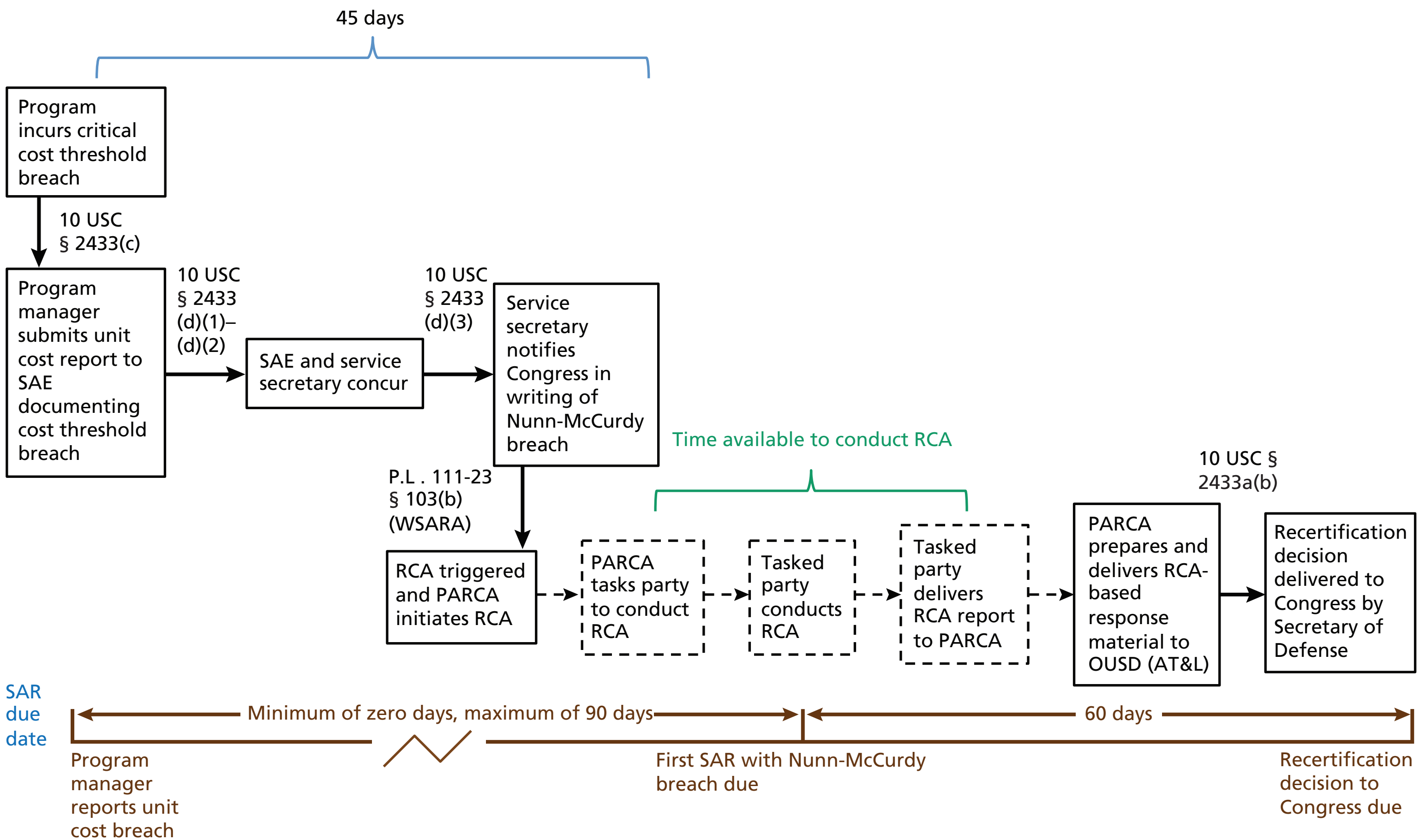
Figure 1.2
Amount of Time Available to Conduct RCAs Can Vary



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Defense's recertification decision to Congress, so RCAs can play a significant role in determining the future course of a program.

Candidate Approaches to Investigating Common Characteristics

Characteristics that may accompany a Nunn-McCurdy breach include quantity changes and schedule delays. We discuss quantity changes to illustrate approaches to uncovering the underlying factors that cause quantity changes to occur.

Of the six RCAs RAND has conducted to date, four incurred unit cost threshold breaches with associated quantity changes. In all four cases, however, quantity change was not the root cause of the unit cost increases. In fact, understanding the principle that quantity change is rarely a root cause for cost growth is fundamental to investigating cases where quantity changes accompany unit cost threshold breaches. The procurement quantity of every major defense system acquisition is a carefully derived number based on the projected requirements for the system. The requirements analysis that supports the quantity is a mandatory activity that occurs before any system enters the acquisition life cycle. Hence, a change in quantity after a system enters the acquisition life cycle occurs only when updated analysis shows an alternative that supports a different quantity. If a quantity decrease occurs, then the research, development, test, and evaluation (RDT&E) costs are spread over fewer units, which results in a higher program acquisition unit cost (PAUC)—the sum of development funding and procurement funding divided by the number of units procured.[12] The root cause of the unit cost growth (higher PAUC) flows not from the quantity change but rather from the assumptions and subsequent decisions based on the updated analysis. The RCA team is charged with uncovering the basis of the assumptions and factors resulting in quantity change decisions based on the updated analysis.

The RAND experience illustrates why we conclude that quantity changes are not the source of unit cost growth.[13] For example, in the case of DDG-1000, the quantity was decreased from ten ships at Milestone (MS) B to three ships when the PAUC breached the critical unit cost growth threshold and triggered the RCA. The DDG-1000 RCA team found that updated perceived changes in the emerging threat and mission priorities, as well as affordability, all key, played roles in the DDG-1000 quantity decrease associated with the PAUC critical threshold breach.

The RAND experience to date also shows that although four programs had associated quantity changes when they incurred Nunn-McCurdy breaches that triggered RCA examinations, in each case the quantity change was grounded in other program-

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12 Average procurement unit cost (APUC) is the procurement funding divided by the number of units procured.

13 See Blickstein et al., 2011, for detailed discussions of the DDG-1000, Longbow Apache, Joint Strike Fighter, and WGS root cause analyses.

specific factors that resulted in unit cost growth.[14] Uncovering the grounds on which quantity changes are founded is an important part of the thorough and insightful RCAs demanded by the WSARA. The RAND experience also points to the importance of understanding the program history, the acquisition environment throughout the program life cycle, and the cost changes that have occurred along the way. The melding of history with cost changes is an important step in an RCA. (See the methodology discussion in Chapter Five.)

Data Sources

The short period of time in which RCAs must be completed points to the importance of timely access to program data. To uncover root causes of unit cost growth, the RCA team must thoroughly understand the entire history of the program, know what key decisions were made and why, comprehend how each significant cost change occurred, link the cost history to key program events, and from this combined knowledge draw out the salient events at the root of the Nunn-McCurdy breach. Timely access to accurate and complete program data is critical, especially in light of the short schedule and need for several individuals to concentrate on a particular aspect of the investigation while keeping abreast of the information being generated by the rest of the team.

Root Cause Matrix

As discussed in our companion report,[15] RAND assembled teams, one for each system, to respond to PARCA's request. Each team undertook two tasks in tandem: establishing the basic facts surrounding the program's Nunn-McCurdy breach or other reported cost growth basis and determining the contribution to unit cost growth of the eight RCA issues stipulated in the WSARA legislation and listed above. The time that elapsed between each program's completion of Milestone B (or applicable counterpart) and the recognition of RCA issues applicable to each program were portrayed in a chart similar to Table 1.1, which illustrates the framework provided by the PARCA office. For these programs under RAND's purview, this figure continues to provide a temporal lens through which RCA issues could be viewed and the analysis informed.

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[14] Though not discussed in detail in this report, schedule slips are another common characteristic that can accompany unit cost breaches. In the case of schedule delays, an RCA team should investigate unforeseen technical issues and changes in procurement environment such as labor disputes, production line problems, or lack of timely availability of raw materials.

[15] See also Blickstein et al., 2011.

Table 1.1
PARCA Root Cause Matrix Framework

	Year from MS B and Fiscal Year					
	B **2001**	**+1** **2002**	**+2** **2003**	**+3** **2004**	**+4** **2005**	**+5** **2006**
Baseline issues						
Unrealistic estimates for cost or schedule		X	X	X	X	X
Immature technology; excessive manufacturing, integration risk		X	X	X	X	X
Unrealistic performance expectations		X	X	X	X	X
Execution issues						
Changes in procurement quantity	X	Change from 150 to 55				
Inadequate funding/ funding instability	X					
Unanticipated design, engineering, manufacturing, or technical issues	X					
Poor performance of government or contract personnel	X					

In addition to the findings for each program, a Navy ERP- and Excalibur-specific version of this chart can be found in subsequent chapters of this report.[16]

The figure arrays the issues specified in the Nunn-McCurdy legislation in the left column and the fiscal years of a notional program whose MS B (or other applicable milestone) occurred in 2001 across the top. An "X" indicates the years in which the event occurred.

As mentioned above, the time line for reporting and certification restricted the amount of data-gathering and analysis that could be performed. To meet PARCA needs, RAND relied on many documents through the course of the project. Some of this material and the program discussion process provided quantitative data, whereas some provided program execution and management decisionmaking insights.

Analysis of each program again identified risk as a common denominator to all programs. As the risks encountered by each program were identified and assessed, sources of program vulnerabilities were collected and compared. Both sets of assigned programs shared some vulnerability, but others were specific to only one.

[16] See also Blickstein et al., 2011, for root cause matrices for the programs examined there.

Of note is the fact that the nature of the risk was modified in the latest two programs examined because neither was a major weapon platform, as was the case with the earlier four programs examined. Further, one of these two, Navy ERP, does not involve a weapon system, but rather is a business process. The other, Excalibur, is a consumable that ties to force structure considerations in a different manner than do major platforms and represents some unique challenges. Our analysis demonstrates the point that some programs need to be considered through a different lens than do others. The Excalibur RCA illustrates that early and inaccurate cost estimates can be detrimental to a program's success, but additional considerations have great value. Although a cost-driven approach to an RCA is well suited for major weapon programs such as the Joint Strike Fighter, additional methods are necessary for expendables such as Excalibur. Chapter Five introduces an approach to risk analysis of technical aspects using the Excalibur program example. Similar to the cost-oriented RCA, the risk analysis is based on a performance time line of select technical components. The time line of technical failures, delays, modifications, and other challenges depicts a longer history of risk than several high-level reports would suggest.

Organization of the Report

This report contains six chapters. Chapters Two and Three report the findings of the RCAs performed by the RAND teams on each of the last two programs under review: Excalibur and Navy ERP. These chapters, idiosyncratic of the specific programs and independent analyses of the teams, reflect the reports that were sent to the PARCA office to be used to carry out its responsibilities and produce both the materials necessary for the recertification decision process as required by OUSD (AT&L), and, ultimately, the Secretary of Defense, as well as memoranda to management addressing issues of concern for consideration as the congressional appetite for oversight and reporting continues to evolve. Chapter Four details an approach designed by the authors to help identify the most critical features of a program. These critical program components are those that carry the most risk of overall program failure. The approach is designed to identify the important program features that decisionmakers would want to concentrate on as the program develops over time. With Excalibur as the example, Chapter Five uses this selective screening of critical components exercise to initially flag the most critical features of the weapon system. This chapter outlines a process for identifying the level of detail particularly appropriate for a specific inquiry effort to uproot program risk. Whereas the process discussed in Chapter Four is designed to identify the critical components of a program that likely contain the most risk, Chapter Five outlines the type of detailed review into those components that may be necessary given the initiating hypotheses. Together, Chapters Four and Five help to frame one approach for considering risk of program failure in programs that have not yet breached. Chapter Six presents our concluding observations.

CHAPTER TWO

Excalibur

This chapter describes the Nunn-McCurdy breach in the Army's Excalibur program (XM982 155mm extended-range guided artillery projectile) encountered in August 2010. The chapter begins with an overview of the Excalibur program. It then describes the general circumstances of the Nunn-McCurdy breach and follows that with a more detailed cost history of the program, including a discussion of RDT&E and procurement cost histories as well as total program costs. The chapter concludes with findings and some considerations for the future.

This analysis of Excalibur's Nunn-McCurdy experience is not intended to be a complete program history and so does not attempt to deal with every element of the program. Rather, we have attempted to identify those aspects of the program that are relevant to the explanation of the Nunn-McCurdy unit cost breaches. In this case, our analysis focuses on reasons for quantity changes throughout the program, technical challenges, and other factors that may account for the cost growth experienced by the program.

Program Overview

Excalibur is an Acquisition Category (ACAT) IC Army munition program that fulfills the Army's requirement for precision fires in an artillery munition. The Army wanted an artillery round compatible with both existing systems (M777A2 lightweight 155mm howitzer and the M109A6 155mm Paladin howitzer) and planned future systems that increased range and accuracy while decreasing collateral damage. The Excalibur product manager reports through the combat ammunition systems program manager, who reports to the Program Executive Officer for Ammunition (PEO-AMMO). The Milestone Decision Authority for Excalibur is the Army Acquisition Executive (AAE).

Excalibur is a complicated acquisition program whose history traces back to the early 1990s. That history has not been untroubled. In the past nearly 20 years, Excalibur has gone through major technical modifications, multiple major decreases in the planned quantity of projectiles, two related program cancellations (Crusader and

NLOS-C), and an acceleration in production initiation to fulfill an urgent requirement in Operation Iraqi Freedom (OIF).

Excalibur's program history began in 1992 with an MS 0 decision in 1992. In 1995, the program was an advanced development program with an entirely different focus from today's. Excalibur evolved from an unguided munition with increased range (1997) to a full global positioning system (GPS) and inertial measurement unit (IMU) guidance kit (to 2010). In May 1997, as an ACAT III program, the initial Excalibur Operational Requirements Document (ORD) was approved along with an MS I/II combined decision. Initial program quantity was 200,000, and Texas Instruments (since acquired by Raytheon) won a competitive selection to serve as the system contractor. The initial engineering manufacturing and development contract with Raytheon TI Systems, Inc., was awarded on January 23, 1998.

In May 2001, the program's ACAT designation changed from ACAT III to ACAT II. In November of that year, the AAE directed that the MS I/II decision be accepted as the official MS B decision. Six months later, the program became an ACAT 1D program with quantity set at 76,677, down considerably from the initial quantity established in 1997. In addition, because of the cancellation of the Crusader program, Excalibur was restructured to include the Future Combat System's non–line-of-sight (NLOS) cannon. Both the quantity and ACAT status were changed shortly thereafter to a quantity of 61,483 in 2003, a 20 percent decrease, and an ACAT status of 1C.

In March 2004, the Excalibur program merged with a joint Swedish/U.S. program known as the "Trajectory Correctable Munitions."[1] This partnership had a positive effect on the program because it enabled the program to overcome some design hurdles. A revised ORD was also approved in September 2004. This revised ORD reflected a major design change with the deletion of the "Dual Purpose Improved Conventional Munitions) variant." This ORD also included the addition of the discriminating munitions variant and a three-increment approach that remains current:

- *Increment Ia-1 projectile*: available for early fielding; met requirements for lethality and accuracy in a nonjammed environment.
- *Increment Ia-2 projectile*: designed to meet requirements for accuracy in a jammed environment, with extended range and increased reliability.
- *Increment Ib projectile*: improved reliability; lowered unit costs; and could be fielded in fiscal year (FY) 14.[2]

[1] Excalibur has an agreement with Sweden in which Sweden contributes development resources. Also, several countries have bought projectiles, including Australia, Canada, and the United Kingdom. In addition, the Marine Corps buys projectiles for use in OIF and Operating Enduring Freedom (OEF) from the Excalibur program manager.

[2] Raytheon Missile Systems developed Increments Ia-1, Ia-2, and Ib. Alliant Techsystems, Inc., developed only Increment Ib. Raytheon produces or will produce all increments.

Subsequently, in October 2004, an acquisition program baseline (APB) was approved that reflected a major reduction in the number of projectiles. A capabilities-based analysis conducted in the work-up to new baseline determined that a procurement quantity of 61,483 rounds was needed. However, the AAE approved the October 2004 APB with an Army procurement objective of 30,000 rounds as supported by the Army Cost Position. This reduction suggests that affordability concerns (i.e., total program cost) were the dominant determinant of the baseline quantity objective.

In March 2005, the Army Resources and Requirements Board validated an urgent needs statement for a precision artillery round, submitted by the Combined Forces Land Component Command.[3] As a result, the program accelerated the fielding and testing of its Increment Ia-1. An MS C Acquisition Decision Memorandum (ADM) was signed in May 2005 with a low rate initial production approval of 500 Block Ia-1 projectiles, and a production contract was awarded in June 2005 to Raytheon for 165 Excalibur Block Ia-1 projectiles. However, Raytheon experienced some quality issues that delayed production and Increment Ia-2 qualification.

These issues also had some negative effects on the program's cost and schedule.[4] Throughout the remainder of 2005, several tests were conducted on Increment Ia-1, and soldier training was initiated. Testing of Block Ia-1 and development of Block Ia-2 continued throughout 2006. After a successful limited user test in February 2007, Increment Ia-2 also passed MS C in July 2007.

In September 2008, the Joint Munitions and Lethality Center awarded two contracts (to Raytheon and Alliant Techsystems, Inc.) for the Increment Ib demonstration phase. At the completion of the first phase, both contractors were required to participate in a shoot-off and competitive down-selection.

The program office fired seven Excalibur Ia-1 projectiles at Yuma Proving Ground in March 2009. This test confirmed that the Honeywell IMU did not meet the Ia-1 performance requirement, so the program transitioned to the Atlantic Inertial Systems (AIS) IMU. While the problem was being rectified, no deliveries were made from November 2008 through August 2009. Overcoming this technical obstacle was a significant achievement for Excalibur. In December 2009, 481 rounds of Excalibur were shipped to theater. Two months later (February 2010), Excalibur completed its initial operational test and evaluation (IOT&E).

In April 2010, the Vice Chief of Staff of the Army Precision Fires Capability Portfolio Review decision reduced quantities further, from 30,000 to 6,264, a decision that the Configuration Steering Board also supported. This decision resulted in a critical Nunn-McCurdy unit cost breach, and a Program Deviation Report was submitted by the Excalibur program manager in July 2010, and notification to Congress

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3 *Excalibur Acquisition Strategy Report,* April 2007, p. 6.

4 Government Accountability Office, *Defense Acquisitions: Assessments of Selected Weapons Programs,* Washington, D.C.: U.S. Government Printing Office, GAO-10-388SP, March 2010, pp. 65–66.

of the breach followed in the next month. Full rate production and initial operational capability (IOC)—both scheduled for 2010—were put on hold until after the Nunn-McCurdy recertification process. However, the recently completed competition to produce the Increment Ib rounds did result in a source selection decision in late September 2010: Raytheon was selected to produce the Increment Ib rounds.

Research Approach

The information used in this analysis was drawn from official primary source documentation. We reviewed a wide range of documentary evidence including ADMs, acquisition strategies, APBs, Defense Acquisition Executive Summary (DAES), SARs, Army budget material, and cumulative earned value management system data on the major Excalibur contracts. Other key information sources included a briefing given to the Nunn-McCurdy Integrated Product Teams, Excalibur's Program Deviation Report (PDR), and the Army's Munitions Mix Study. In addition, we interviewed program office personnel and OSD officials. Finally, we conducted a thorough search of the trade literature and Government Accountability Office (GAO) audits of the program. Sources used in this RCA appear in the list of references at the end of the report.

Cost History

This section discusses the cost history of the Excalibur program, beginning with the unit cost breaches that triggered the need for this root cause analysis. We also examine how RDT&E and procurement costs have changed over time and, to the extent possible, identify factors affecting those changes.

The Nunn-McCurdy Breaches

On August 20, 2010, the Secretary of the Army officially reported to Congress that the Excalibur program had experienced unit cost growth exceeding the critical statutory unit cost growth thresholds. A reduction in the planned total quantity from 30,000 to 6,264 projectiles resulted in these unit cost breaches, and the Excalibur program entered the Nunn-McCurdy recertification process. This process was updated by Congress in the WSARA of 2009 to include a root cause analysis conducted by the newly established PARCA office.

In accordance with 10 USC § 2433, the Army notified Congress that based on a July 6, 2010, Program Deviation Report, an approximately 890 percent reduction in quantity resulted in Excalibur unit cost growth exceeding the critical statutory acquisition program baselines.

The Excalibur program incurred four critical Nunn-McCurdy breaches:

- The APUC exceeded the current 2007 APB by 115.91 percent.
- The PAUC exceeded the 2007 APB by 181.34 percent.
- The APUC exceeded the original 2004 APB by 143.59 percent.
- The PAUC exceeded the original 2004 APB by 193.06 percent.[5]

The 2009 WSARA requires a root cause analysis process on programs that incur critical breaches.[6] The "speeding ticket" addressed by the Excalibur root cause analysis is shown in Table 2.1.[7]

Research, Development, Test, and Evaluation Cost Profiles

The Excalibur RDT&E funding line included development of all Excalibur variants and technology upgrades. In addition, a number of other efforts share the Excalibur RDT&E funding line. These include the Spin Stabilized Sensor Fused Munition (SSSFM); nonlethal munitions; a program to evaluate smart submunitions for potential cannon, missile, and rocket applications; and the 105mm cargo projectiles that were added by Congress in FY2008–FY2009. Despite the large scope of RDT&E included, the congressional addition of the 105 projectile, and the technologically significant development of the Excalibur variants, RDT&E funding has been fairly stable. A notable exception is the extension of RDT&E funding beyond 2008 starting with the December 2003 RDT&E funding profile.

Figure 2.1 shows the RDT&E funding profiles from all of the Excalibur SARs from December 2002 through December 2009 and the August 2010 DAES.[8] Other than the extension of funding to years past 2008, the profiles are all close to each other, indicating stable annual RDT&E funding. The chart also shows RDT&E quantities associated with some profiles. Though RDT&E quantities increased several times, there was little notable RDT&E cost growth as a result. In general, the planned RDT&E expenditures for a given year were spent according to plan.

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5 For the purposes of this report, the current estimate cost data are taken from a DAES/Web Services current status report downloaded from Defense Acquisition Management Information Retrieval (DAMIR) on August 24, 2010. An Excalibur September 2010 draft SAR posted on DAMIR in October contains slightly different current estimate cost and quantity data. The September 2010 draft SAR shows that the APUC exceeded the 2004 and 2007 baselines by 159 percent and 130 percent, respectively, and the PAUC exceeded the 2004 and 2007 baselines by 211 percent and 199 percent, respectively. Total procurement quantity is shown as 6,506 vs. the 6,905 shown in the August 2010 DAES. In both documents, the RDT&E quantity is shown as 544 rounds. Although these cost growth numbers are higher than those reported in the August DAES, the more recent current estimate does not change the analysis or findings of factors affecting unit cost growth presented here.

6 Public Law 111-23, May 22, 2009.

7 Speeding ticket is the term used by the PARCA office to describe the event that triggers the need for an RCA.

8 The August 24, 2010, DAES contains the latest DAES information available as of this writing.

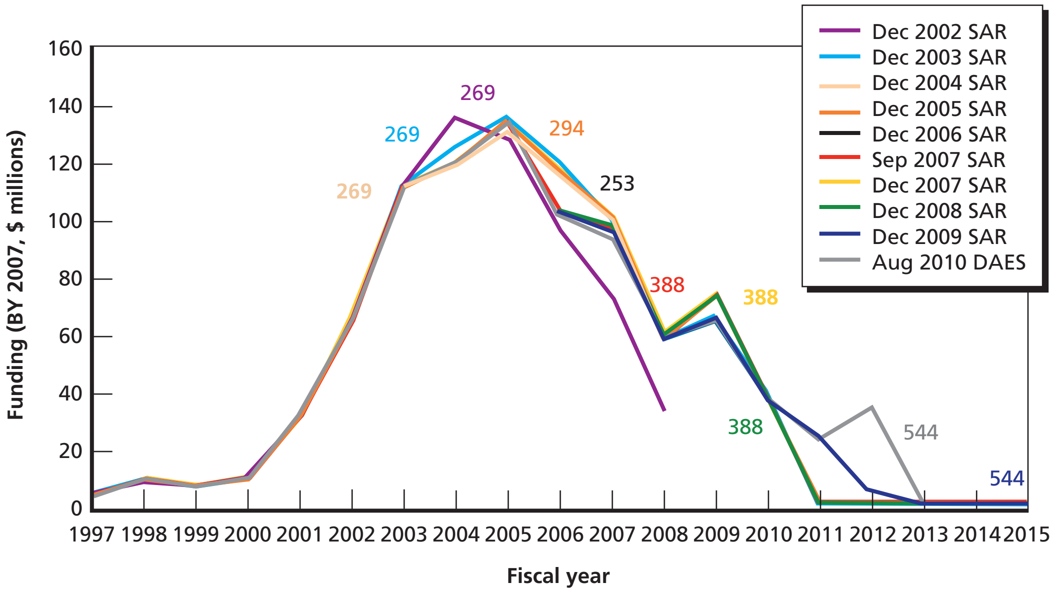
Table 2.1
Excalibur "Speeding Ticket"

			Cost Growth Threshold Breaches						
Program	**Baseline Unit Cost (FY 2007 $ thousands)**	**Current Estimate (August 2010 SAR) FY 2007 $ thousands)**	**Baseline Breached**	**Percentage**	**Amount of Unit Cost Change**	**Level**	**Baseline Quantity**	**August 2010 DAES**	**Immediate Cause in August 2010 DAES**
Excalibur	APUC $44.40 (2007 APB)	APUC $94.76	Over current baseline (2007 APB)	APUC +115.91%	+$51K FY 2007 $K	Critical	30,000	6,905	Quantity decreased to 6,905 units
	PAUC $74.52 (2007 APB)	PAUC $211.32		PAUC +181.34%	+$136K FY 2007 $K	Critical	30,388	7,449	
	APUC $39.43 (2004 APB)	APUC $94.76	Over original baseline (2004 APB)	APUC +143.59%	+$56K FY 2007 $K	Critical	30,000	6,905	
	PAUC $71.61 (2004 APB)	PAUC $211.32		PAUC +193.06%	+$139K FY 2007 $K	Critical	30,269	7,449	

SOURCES: Department of Defense, *Defense Acquisition Executive Summary*, August 24, 2010; Department of Defense, *Defense Acquisition Executive Summary,* July 29, 2010; Under Secretary of the Army, *Excalibur Program Acquisition Decision Memorandum,* May 12, 2010; Department of Defense, *Selected Acquisition Report Excalibur,* December 31, 2009; Department of Defense, *Selected Acquisition Report Excalibur,* December 31, 2007; Department of Defense, *Selected Acquisition Report Excalibur,* September 30, 2007; Department of Defense, *Selected Acquisition Report Excalibur*, December 31, 2006; Department of Defense, *Selected Acquisition Report Excalibur,* December 31, 2005; Department of Defense, *Selected Acquisition Report Excalibur*, December 31, 2004; Department of Defense, *Selected Acquisition Report Excalibur,* December 31, 2003; Department of Defense, *Selected Acquisition Report Excalibur,* December 31, 2002.

NOTE: The numbers in red indicate the "speeding ticket" triggering root cause analysis by PARCA.

Figure 2.1
Excalibur RDT&E Funding Profile



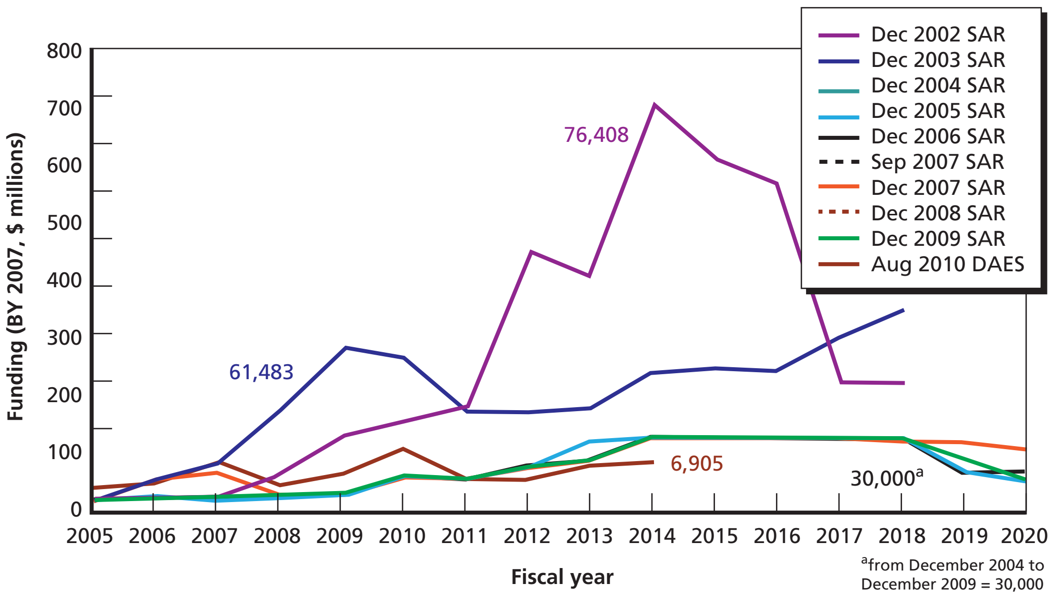
SOURCES: Derived from Excalibur SARs, December 2002 to December 2009; Excalibur DAES, August 24, 2010 (downloaded from DAMIR).
NOTE: BY is base year.
RAND *MG1171/2-2.1*

Procurement Cost Profiles

Annual Excalibur procurement funding was also fairly stable from 2004 to 2009 (see Figure 2.2). The December 2002 and December 2003 SARs show marked changes in the procurement funding profiles after 2007. These differences likely result from the reduction in procurement quantity from 76,408 units in 2002 to 61,483 units in 2003, and then to 30,000 rounds in 2004.[9] The Army procurement quantity objective remained constant at 30,000 units from 2004 through 2009, and the procurement funding profile did not change significantly during these years. The August 2010 DAES reflects the procurement reduction to 6,905 units, and the procurement funding profile in the August 2010 DAES shows that the change is reflected in a truncation of procurement funding after 2014.

[9] The total procurement quantity is actually 6,905 and is composed of 6,264 production rounds, 242 rounds fired during production acceptance testing, and 399 rounds of foreign military sales buy-back. From a unit cost point of view, 6,905 rounds is the relevant total quantity number.

Figure 2.2
Excalibur Procurement Funding Profiles



SOURCES: Derived from Excalibur SARs, December 2002 to December 2009; Excalibur DAES, August 24, 2010 (downloaded from DAMIR).

RAND *MG1171/2-2.2*

The increase in Increment Ia-1 and Ia-2 rounds and associated production acceleration in support of the urgent operational need in OIF/OEF is not noticeable in the annual funding profiles.[10]

Total Program Funding and Quantity Profiles

As might be expected, the total Excalibur funding profile is shaped by the procurement profile. Figure 2.3 shows a synthesis of the RDT&E funding, procurement funding, and total RDT&E and procurement quantity profiles. After the large decrease in procurement funding from 2003 to 2004, the ratio of procurement to RDT&E funding stayed roughly the same through 2009, with procurement accounting for 57–61 percent of total program costs. With the latest reduction in quantity, this ratio has reversed; RDT&E now accounts for 58 percent of total Excalibur program costs versus the previously roughly 40 percent.

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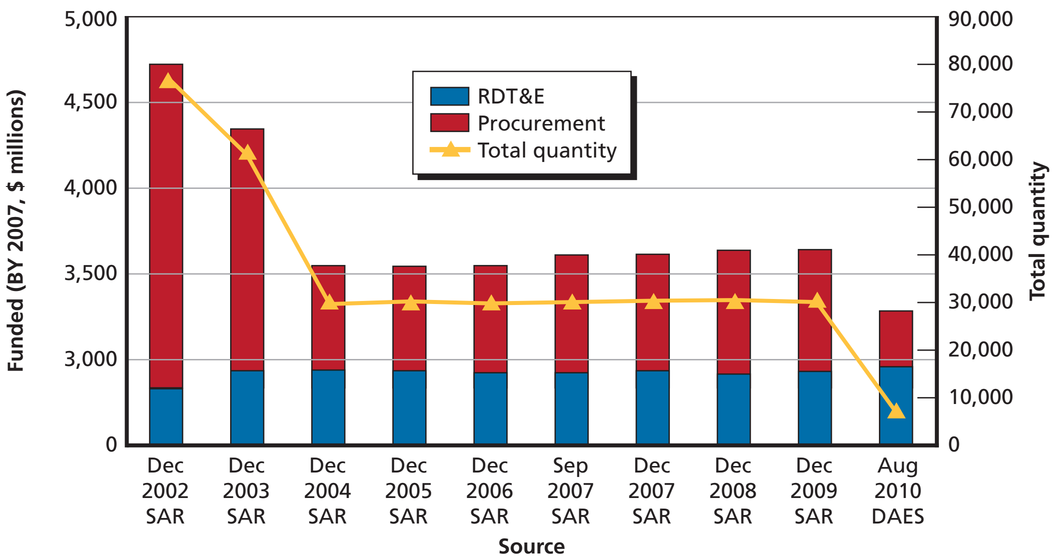
[10] The 2006 and 2009 SARs identify a small amount of funding that appears to support the urgent need request: $14.1 million and $11.7 million, respectively (BY 2007 dollars). We have not been able to find documentary evidence of additional funds beyond this.

Figure 2.3
Excalibur Total Program Funding and Quantity Profiles



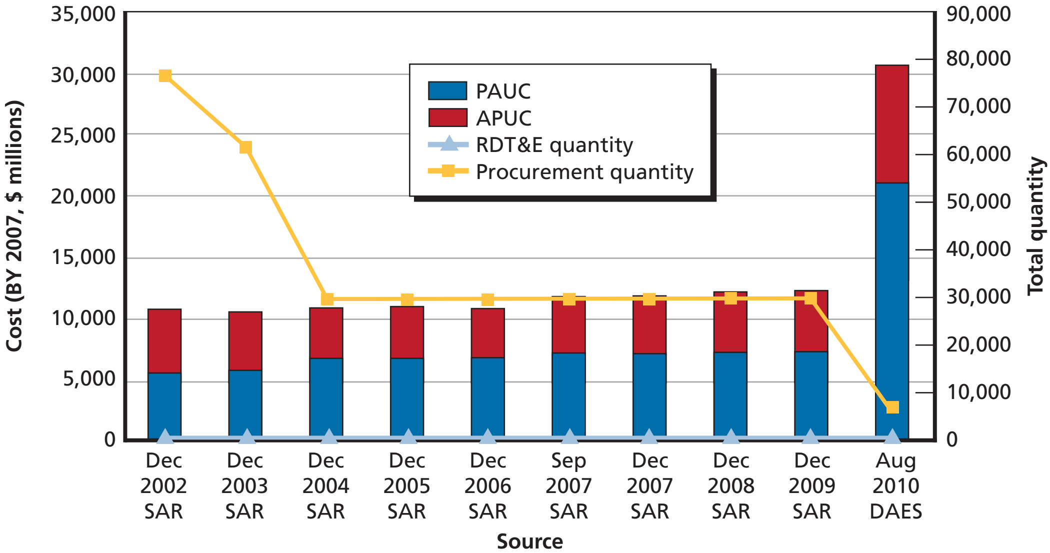
SOURCES: Derived from Excalibur SARs, December 2002 to December 2009; Excalibur DAES, August 24, 2010 (downloaded from DAMIR).
RAND *MG1171/2-2.3*

Unit Cost Profile

The SAR data show that both the APUC and PAUC remained fairly stable from December 2002 through December 2009 (Figure 2.4). Of note is the slight increase in the PAUC from 2002 to 2003, whereas the APUC decreased slightly during the same period. The difference between the PAUC and APUC then remained fairly constant until August 2010 when the Army formally declared unit cost growth breaches. The large reduction in quantity first reported in the August 2010 DAES is reflected in the large increases in APUC and PAUC.

Figure 2.4 shows the APUC, PAUC, and quantity profiles. Both cost metrics should be sensitive to changes in procurement quantity. Nevertheless, the very large quantity reductions in 2003 and 2004 did not result in any significant change to either APUC or PAUC. This suggests that the early unit cost estimates were not based on a complete analysis. The procurement funding change from 2002 to 2004 represents a 67 percent reduction from the 2002 amount, but neither unit cost metric changed much at all. This insensitivity also calls into question the realism of the unit cost goals through 2009. To date, we have uncovered no additional funding sources that may have been used to cover costs but are not included in the sources we examined for this analysis.

Figure 2.4
Excalibur Unit Cost Profiles



SOURCES: Derived from Excalibur SARs, December 2002 to December 2009; Excalibur DAES, August 24, 2010 (downloaded from DAMIR).

RAND *MG1171/2-2.4*

RDT&E History

Figure 2.5 shows the total program estimated RDT&E costs for Excalibur since 2002. The large increase from 2002 to 2003 was due to "the addition of Block Ib of the spiral development previously unfunded (Engineering)."[11] In other words, Block Ib development had been planned, but it was not funded in the program budget until 2003. After that increase, the RDT&E budget appears to have remained largely stable. There were multiple minor inflation and budget adjustments as well as increases in the number of test rounds, but these changes were relatively small and effectively canceled each other out. The exception is the additional development test quantity change from 388 to 544 to "account for additional planned system-level Increment Ib test rounds."[12] The reason for the $23.8 million (BY 2007 dollars) increase from 2009 to 2010 is unknown.[13]

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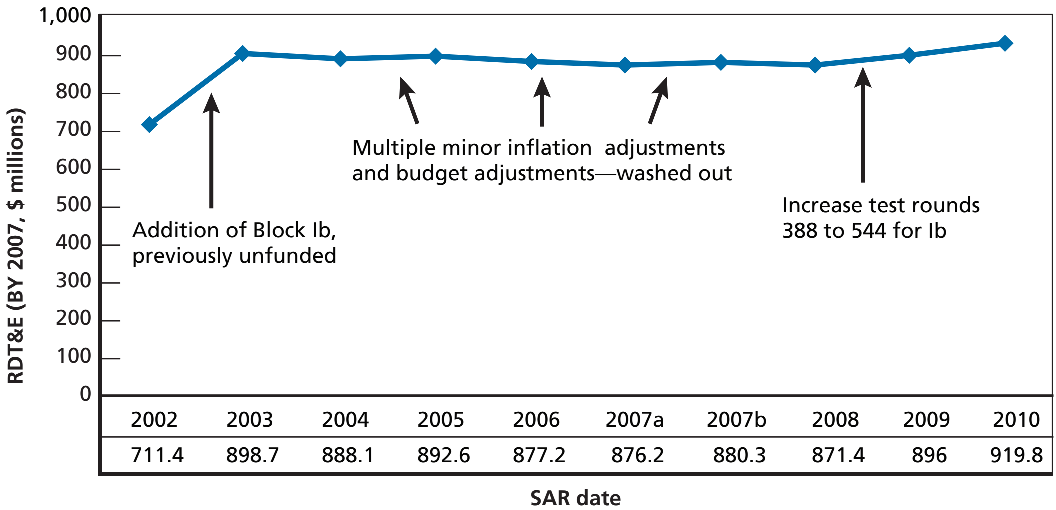
[11] Excalibur December 2003 SAR cost variance table current change explanations.

[12] Excalibur December 2009 SAR cost variance table.

[13] It is possible that this increase is driven by changes in the buy profile for the RDT&E rounds, but we do not have documentary evidence. The August 24, 2010, DAES (from DAMIR) shows a buy profile for development rounds but previous SARs do not.

Figure 2.5
Excalibur Total Program RDT&E History



SOURCES: Derived from Excalibur SARs, December 2002 to December 2009; Excalibur DAES, August 24, 2010 (downloaded from DAMIR).
RAND *MG1171/2-2.5*

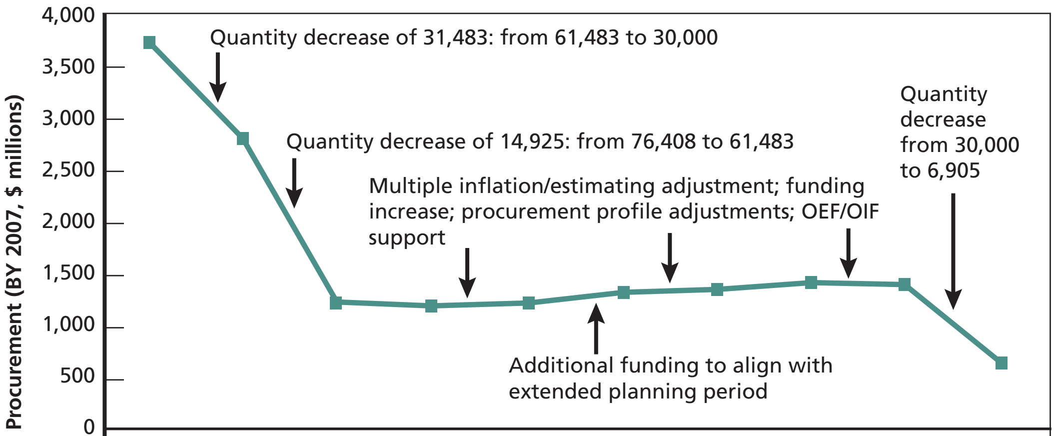
Procurement History

Figure 2.6 shows the procurement history for Excalibur from 2002 to 2010. The three very large decreases in total quantity clearly drive the cost increase. The first two quantity decreases resulted in a 68 percent reduction in procurement costs from what was planned in 2002. As mentioned above, it is interesting that such a significant reduction in quantity appears not to have affected unit cost. The last quantity decrease—the nearly 80 percent decrease that resulted in the Nunn-McCurdy unit cost breaches—reduced total procurement costs by 52 percent of what had been planned in 2009. It also resulted in a situation in which the total program RDT&E funding ($919.8 million, BY 2007 dollars) is about one-third higher than the total procurement funding ($654.3 million, BY 2007 dollars).

Figure 2.6 also shows the relatively minor growth (17 percent) in total estimated procurement cost that occurred over the period 2004 to 2009. Procurement quantity was fixed over this period at 30,000. Factors other than quantity accounting for this 17 percent increase include the following:

- additional funding to address an urgent need for early fielding
- multiple small inflation adjustments over the period
- changes in production profile (number procured each year, production stretchout).

Figure 2.6
Excalibur Total Program Procurement History, 2002–2010



2002	2003	2004	2005	2006	2007a	2007b	2008	2009	2010
3,727.3	2,800.4	1,196	1,193.5	1,208.1	1,352.2	1,352.2	1,430.4	1,402.4	654.3

RAND *MG1171/2-2.6*

The largest increase occurred in 2007 (as reported in the September 2007 SAR): $141.5 million (2007 dollars) associated with the approved production baseline (July 2007 APB). Specifically, the September 2007 SAR states that the program "received additional program funding primarily in the extended planning period to align with the agreed Army Cost Position and APB agreement (Estimating)."[14]

Findings[15]

Excalibur formally began in May 1997 as an ACAT III program with approval of Milestone I/II, which included approval of an ORD and other documentation required of an ACAT III program. The program was structured as an incremental development in three blocks, defined by the characteristics of the warhead: Block I was a unitary warhead, Block II was a smart warhead, and Block III was a discriminating warhead.

The original Excalibur concept differed significantly from the current one. The original concept focused on increasing range by means of a rocket-assisted base con-

[14] See the cost variance table in the Excalibur September 2007 SAR. A large procurement variance was reported in the December 2004 SAR: $164.5 million (then-year dollars) associated with a "stretchout of the annual procurement buy profile (Schedule)." According to the December 2004 SAR, the cost impact was recorded only in then-year dollars, with no impact to the base year dollar estimate.

[15] All dollar figures in this section's narrative are expressed in base year 2007 dollars.

figuration, rather than on increasing accuracy. It was "self-locating," with GPS and transceivers planned for only one-sixth of the total number of rounds. However, the initial contract to Texas Instruments (later purchased by Raytheon) in January 1998 reflected a significantly different concept and included GPS, an IMU, and fin-and-canard gliding airframe technology.[16] The initial low cost estimate and high-quantity target appear to have resulted from a presumption that the system did not differ much from older nonprecision artillery rounds.[17] However, the two later baselines (APBs approved in October 2004 and July 2007) appear to contain cost and schedule estimates more consistent with the capabilities of the current Excalibur system.

Root Cause Analysis

Early program cost estimates were highly inaccurate, as demonstrated by the insensitivity of unit cost estimates to significant reductions in quantity in the early program.

Quantity reductions before 2002[18] and in 2003 and 2004 appear to have been driven by affordability concerns. Until the recent Munitions Mix Study (formally, the Precision Munitions Resourcing Strategy Study conducted by the Center for Army Analyses), the only capabilities-based requirements analysis mentioned by program officials or in program documentation was one in 2004 that recommended a quantity of 61,483.[19] This requirements analysis was performed as part of the activities leading to Excalibur's first ACAT I baseline, eventually approved in October 2004. However, that baseline (the development baseline) included an Army procurement objective of 30,000 rounds. The procurement quantity objective of 30,000 remained the official objective until the May 2010 ADM reduced the quantity to 6,264.

According to cost variance reported in the Excalibur SARs from 2002 to 2009, the program experienced relatively minor cost growth in both RDT&E and procurement accounts. As reported in the December 2009 SAR, the APUC grew to 20.5 percent above the October 2004 APB (from $39,000 to $47,000 in BY 2007 dollars) and 6.8 percent above the July 2007 APB (from $44,000 to $47,000 in BY 2007 dollars). Factors affecting cost growth during this period included budget adjustments, programming for unfunded development rounds, and additional funding to support a validated urgent operational need (which included accelerating the production of Increment Ia-1 rounds and procuring more of those rounds than originally planned). There were also some technical difficulties experienced during developmental testing,

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16 The addition of the GPS and IMU added important technical complexity to the project. An early risk analysis could have raised warning flags about the project's likelihood of success.

17 *Excalibur Acquisition Strategy Report,* April 2007.

18 According to discussions with program officials and GAO MDAP reports, quantity estimates before 2002 range from over 200,000 rounds to 76,000 rounds.

19 This quantity (61,483 rounds) appears as the current estimate in the Excalibur December 2003 SAR.

production process challenges, relocation of contractor facilities, and replacement of the IMU vendor.

Because of the abbreviated amount of time available to conduct an RCA, these cost growth factors were not initially evaluated. However, RAND subsequently developed a complementary methodology for considering them as well as a way to understand the nature of technical risk. Chapter Four of this report describes the complementary methodology, and Chapter Five characterizes technical risk and how it may be evaluated better.

None of these factors appears to have influenced the May 2010 decision to reduce the Army's procurement objective from 30,000 to 6,264, triggering the Nunn-McCurdy breach. Rather, that quantity reduction decision appears to be the result of several other factors, including the Precision Fires Capability Portfolio Review (also called the Munitions Mix Study), the Quantitative War Reserve Requirements Munitions Model Process, and reportedly low use of the Increment Ia-1 round in theater.[20]

These three influential factors suggest a combination of requirements change and affordability considerations as the drivers of the decision to reduce the Army's procurement objective by 79 percent and thus are the root causes of the Nunn-McCurdy breaches in PAUC and APUC. The rationale for reducing the quantity from 30,000 to 6,264 units includes analysis that incorporated a change in operational concept that significantly reduced quantity requirements. Specifically, there was a change in the manner in which the artillery is used, and the precision of the Excalibur unit meant that fewer units would be needed. Additionally, the Munitions Mix Study evaluated Excalibur within the context of other Army systems that also provide precision fires capability, rather than as a stand-alone (independent) precision fires capability. Affordability also appears to have been a factor, particularly in light of the increased pressure on the Army procurement budget.

Table 2.2 shows the PARCA root cause matrix for Excalibur. The cells where text is present indicate that the factor in the first column was active during the time period indicated in the column heading (first row). The matrix summarizes the narrative given above.

- The original May 1997 cost estimates appear to have been highly inaccurate.
- The initial SAR cost estimates were not much more accurate, as evidenced by unit costs being unaffected by the 20 percent quantity reduction in 2003 and the subsequent additional 51 percent quantity reduction in 2004.
- A concept and technological change appears to have occurred for the Excalibur system between the original solicitation and the contract award to Texas Instruments in January 1998.
- The high level of performance envisioned for Excalibur turned out to be feasible.

[20] See the May 12, 2010, ADM; July 6, 2010 Program Deviation Report; and Congressional Notification Letters.

Table 2.2
PARCA Root Cause Narrative Matrix for Excalibur

	MS I/II May 1997	ACAT I 2002	APB October 2004	APB Revisions September 2007	ADM May 2010
Baseline issues					
Unrealistic estimates for cost or schedule	May 1997 estimates highly inaccurate	Estimate not reflective of current system			
Immature technology; excessive manufacturing, integration risk	Concept and technology change from solicitation to contract award with Texas Instruments in January 1998				
Unrealistic performance expectations					
Execution issues					
Changes in procurement quantity		Reduced 10% to 61,483 from 76,408	Reduced 51% to 30,000 from 61,483		Reduced 79% to 6,264 from 30,000
Inadequate funding/ funding instability			Addition of Block IB unfunded		
Unanticipated design, engineering, manufacturing, or technical issues		Minor technical issues	Minor technical issues	Minor technical issues	Minor technical issues
Poor performance of government or contract personnel	X				
Other					Urgent operational need to OEF/OIF caused production acceleration and more Increment Ia rounds

- The quantity reductions from the original 200,000 to 76,408 appear to have been driven by affordability concerns.
- A subsequent reduction in the Army's procurement objective from 76,408 to 61,483 was the result of a capabilities-based requirements analysis in 2004 that recommended the 61,483 quantity. The Army Munitions Mix Study is cited by

the Army as the capabilities-based analysis supporting the most recent 79 percent quantity reduction to 6,264 units.

- The Excalibur program experienced relatively minor technical issues from 2002 to the present. These issues include replacement of an IMU vendor and survivability of the electronics when a round was fired. These technical problems contributed to some cost growth but were not significant factors in the Nunn-McCurdy breach.
- The performance of government and contractor personnel appears to not have been an issue, with the possible exception of the IMU vendor replacement.
- Finally, the only other factor influencing Excalibur unit cost growth is the validated urgent operational need for OEF/OIF, which caused production to be accelerated and the production of more Increment Ia rounds than originally planned.

Caveats and Future Risks

Additional documentary evidence would increase confidence in the root cause analysis described above. Specifically, the rationale for the 79 percent reduction in the Army's procurement objective from 30,000 units to 6,264 units is required. The Concepts Analysis Agency of the U.S. Army study refers to a "minimum buy" of Excalibur without defining this term and without an explanation of how it was calculated. Insights into how this figure was determined would bolster the analytic support of the root cause analysis.

In addition, the CAA charts show that a unit cost of $40,000 was used for the analysis. The CAA study does not indicate what year dollars the $40,000 figure is in, but it is not consistent with any PAUC or APUC uncovered to date. An explanation of why this unit cost was used and how it was calculated or a reference for it would help explain how analysis based on a seemingly different unit cost supports the quantity reduction.

Marine Corps buys of Excalibur appear to have been in the 1,000-unit range. When the Army procurement quantities were in the 30,000 range or higher, the Marine Corps buy would have represented less than 4 percent of the total and could have been expected to have had very little effect on the Excalibur unit cost. However, given that the Army buy is in the 7,000-unit range, the Marine Corps buy of about 1,000 units represents a much larger portion of the total production and hence should have a noticeable effect on unit cost. When the Marine Corps buy is considered along with the foreign military sales quantities, then the sum of these external quantities can logically be expected to have a significant effect on unit cost. Additional documentary evidence is needed to explain how the Marine Corps and foreign military sales are being accounted for to gain a full understanding of the true unit cost of Excalibur.

Finally, Army budget documents indicate that the Army has received supplemental funding to support the validated urgent operational need. Additional documentation that provides a complete accounting for all funds, regardless of origin, expended

or planned to be expended for Excalibur rounds would help provide a full understanding of the true unit cost of Excalibur rounds. Again, those data were not available to RAND in the allotted time for this RCA.

However, as noted above, our experience in analyzing events with regard to Excalibur RCA findings led RAND to develop new techniques to assess the relative contribution of risk to a program from its various and often complex component systems. Chapters Four and Five of this report present complementary views for examining risk of program failure within these complex systems. Chapter Four describes an exercise for using the technical complexity of a program and its level of detail to assess risk and identify the most critical features of a program. It shows that by narrowing the scope of the decisionmaker's review to a handful of the most critical components, the incremental technical risks that may lead to major failures could be identified and possibly averted.

Chapter Five demonstrates a process of taking the more narrowly defined review path, crafted as a result of the exercise outlined in Chapter Four, to explore the technical level of risk within the most critical components. Using the Excalibur as an example, Chapter Five demonstrates that by focusing the decisionmaker on the IMU and the GPS receiver components, the incremental problems that ultimately became detrimental to the Excalibur system would have been visible early in the program's history. By identifying the incremental problems that plague the most critical components, decisionmakers might have been able to correct the program's path before it breached. Considered together, Chapters Four and Five present a process for identifying the critical components and then determining how best to sift through their data for any underlying challenges or otherwise unknown weaknesses.

Remaining Risks to Monitor

Two risk areas in our analysis warrant monitoring: Increment Ib rounds and the ability to achieve cost goals for Increment Ib using planned manufacturing processes.

The source for Increment Ib was selected at the end of August 2010, with a contract award to Raytheon immediately after. Only a limited number of rounds were fired as part of the competition. Some additional testing is needed to get a better understanding of the Increment Ib round's actual performance. Although the development risk appears to be low, it still should be monitored.

The ability to achieve Increment Ib cost goals using the planned manufacturing processes also requires attention. The most significant change in the Increment Ib round is how it is manufactured. The changes are intended to reduce the cost of Increment Ib production to half that of Increment Ia rounds. Changes in manufacturing processes carry some risk and should be monitored. If the expected dramatic reduction in production cost cannot be attained, then the current unit cost estimates will be too low and the program will again experience growth in the unit cost metrics.

CHAPTER THREE

The Navy Enterprise Resource Planning Program

This chapter considers cost growth in the Navy ERP program. It begins with a discussion of ERP programs in general, provides an overview of the Navy ERP, and presents its cost history, including increases, program changes, and schedule delays. It then assesses the program's risk and draws some policy lessons. Because the ERP was not a Nunn-McCurdy breach, more time was available to study it than was available for the other RCAs. Thus, the analysis considers other aspects of the program or goes into greater depth than was possible for programs with short congressional deadlines.

Enterprise Resource Planning Programs

An ERP program is a software suite designed to provide an organization with data that can be aggregated across its "enterprise." By enforcing standard data definitions across an enterprise, the software collects data in a format inherently amenable to aggregation. The redefined and formatted data allow organizations to measure their processes and results in ways that their discrete management and related information technology systems could not, thus facilitating a synoptic view. ERP implementation, as a result, moves the burden of work from (blue collar) data entry to (white collar) data analysis.

Today, ERPs are sold generally as prepackaged, commercially available software intended to merge data seamlessly from a multitude of sources. In its current form, ERP software has been built to accommodate a set of standard organizational functions; acquirers of the software can select the prepackaged capability that most resembles their business. Once acquired, this software is then configured further to match the specific business processes of the user.

It is easy to think of an ERP as just another information technology acquisition, but that is a misleading perspective. Because of the "enterprise" nature of the ERP program, implementing one effectively invariably requires two steps: understanding existing business processes well enough to define accurately the nonstandard data that exist currently, and re-engineering business process as to best practices and thereby producing standard data in the future. The first step is crucial for understanding thoroughly the reason data exist in the current format and for eliciting what processes are

essential for maintaining an efficient and effective business structure. (Divergent data often indicate that extant business processes do not correlate well.) End results of the second step differ for each organization that implements an ERP; an inherent trade-off exists between software customization and business process alteration, with the latter offering a greater degree of standardization.

End-to-end business processes must be standardized to create data that can be aggregated from disparate organizational components. By acting as a tool to hold business data, the ERP also serves as a forcing function to identify nonstandard processes within its domain. These nonstandard processes can be altered to conform, or the ERP software can be modified to accommodate a one-off solution. Thus, to implement an ERP, organizations must necessarily understand not only what their business processes are but also what they ought to become. Self-understanding is never easy, and this process is particularly challenging in an institution such as the U.S. Navy, which is very large, very old, and uses complex processes representing, in part, many deep cultural norms, which vary from one command to another.

Therein lies an important circularity. Estimating the cost of acquiring and, more importantly, implementing an ERP requires understanding current business processes (as well as how they might evolve). But a major cost of implementing an ERP is doing precisely that: understanding one's business processes well enough to standardize them for the ERP program. In other words, to estimate the cost of program implementation requires actually implementing at least the front end of the program. ERP implementation includes acquisition of the "tool" and business process alteration, yet the ability to estimate the cost of business practice change depends heavily on the knowledge of the individuals involved in the program. The current difficulties faced by the Department of Defense (DoD) in implementing ERP programs on time and under budget reflect, in part, this dilemma.

The Navy ERP program, initiated in 2003 and fully started in 2004, was designed to serve as the technical backbone for the maintenance, financial, and supply functions of the Navy. Although it is currently nearing complete implementation, the history of the program reveals that its cost has risen and its schedule has lengthened beyond original estimates. As a result of increased scrutiny on the government's acquisition of ERP systems, this chapter attempts to shed light on the root causes for Navy ERP problems based on standard MDAP metrics; it also addresses the topic of whether MDAP metrics are the appropriate indicators of ERP program problems.

Overview of the Navy ERP

The Navy's ERP program had its genesis in the late 1990s, when the combination of shrinking budgets and the added turbulence created by base closures and other realign-

ments within the Navy prompted officials to turn to a new class of software, ERP software, as a way to gain mastery over its support functions.

Although the purported purpose of the pilot ERP varies based on stakeholder viewpoint, four purposes appear fundamental.

- The first was to gain a modernized capability to manage System Commands' (SYSCOMs') post-1995 Base Realignment and Closure (BRAC) consolidations and realignments. Most legacy information systems were written in COBOL, which was becoming increasingly expensive to maintain. BRAC necessitated a major overhaul of existing management and information systems, thus providing an opportunity to upgrade to an ERP program.
- The second was to start the process toward gaining a global visibility over the data in the Navy's support base, notably financial records, supply, and repair. This visibility would allow for better informed policy analysis to provide more efficient operational decisions, driven, in part, by DoD-wide pressure to improve management.
- The third was to achieve "clean financials," a completely reconciled picture of accounts, assets, disbursements, receivables, and so on. This goal was pursued to achieve conformance with the Chief Financial Officers (CFO) Act of 1990[1] and because cleaner accounts allowed program and financial personnel to be shifted from tedious reconciliation duties to putatively more productive analytic tasks.
- The fourth was to liquidate negative wedges. These were created in the later half of the 1990s as a function of the Defense Management Review process under Secretary of Defense Cheney. This review postulated savings opportunities and reduced budget top-lines in an anticipatory manner as an incentive to command performance.

From the outset, the Navy realized that the challenges of ERP program implementation were going to differ substantially from those experienced by the private sector because of its size and diverse scope of business functions. It therefore authorized four of its SYSCOMs to start pilot ERP programs. Table 3.1 lists each SYSCOM, its pilot, what each was designed to do, and its estimated cost (bear in mind that roughly half of these costs were for day-to-day operating expenses). The Navy also recognized the inherent complexity of this project. The number of users was large (~140,000), a significant amount data had to be converted and legacy data cleansed, processes included over 1,300 unique transactions, the amount of data involved exceeded 15 terabytes, and the transaction volume was large—over 32 million transactions per month.

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[1] For more information, see Public Law 101-576, Chief Financial Officers Act of 1990, November 15, 1990, or General Accountability Office, The Chief Financial Officers Act: A Mandate for Federal Financial Management Reform, September 1991.

Table 3.1
ERP Original Pilot Efforts

Command	Name	Purpose	Cost[a]
Naval Air Systems Command (NAVAIR)	SIGMA	Program management, contracting, financial, and time/attendance	$215.9
Naval Supply Systems Command (NAVSUP)	SMART	Supply management for the LM-2500 engine and the EA-6	$346.6
Space and Naval Warfare Systems Command (SPAWAR)	CABRILLO	Financial management	$67.4
Naval Sea Systems Command (NAVSEA)	NEMAIS	Intermediate maintenance management	$414.6

SOURCE: Government Accountability Office, *DoD Business Systems Modernization: Navy ERP Adherence to Best Business Practices Critical to Avoid Past Failures,* Washington, D.C.: U.S. Government Printing Office, GAO-05-858, September 2005.

[a] Millions of dollars; through FY 2004.

In 2003, the Navy concluded that the pilot programs, which viewed their "enterprise" boundaries at the SYSCOM level, had run their course and that it was time to merge their results into a converged Navy ERP program, whose process standardization would span SYSCOMs. Part of the impetus was that the Navy had grown more confident in its understanding of ERP programs. Another factor may have been dictates from the OSD Comptroller's office to the military departments requiring that the latter re-engineer their systems to produce clean financials. [2] The Navy concluded that the governance structure of the separate ERP programs in the various SYSCOMs—operating different schema with processes optimized only at the SYSCOM level—lacked the unity and coordination required for these mandates. The Navy's analysis indicated that integrating the pilot ERP systems would be more costly and less effective than starting anew with a single Navy ERP program office. It designed a hierarchical governance structure to optimize processes *across* SYSCOMs, under service-wide funding, using a standard software platform (produced by the German company SAP, which, it turns out, was the software backbone selected by each pilot program contract integrator and used for each of the four SYSCOMs' pilots).[3] To develop the parameters of the Navy ERP, the program office brought ERP teams from the four SYSCOMs to work together and determine collectively which features in each of their programs were

[2] Although the pilot ERPs were meant to enable cleaner financials, it was known that they would not produce auditable records by themselves.

[3] Analytically, it could have been useful to analyze the Navy ERP as a conglomeration of each SYSCOM's ERP, each with its own budget and milestone. Such a record may have indicated whether one or another SYSCOM had a greater cost growth or a longer schedule slip than its counterparts—something that might have shed light on whether differences in implementation among SYSCOMs may have been correlated with better or worse performance. However, the Navy does not keep the ERP budget that way, in large part because there were many functions, such as help desks, that are common across programs.

worthwhile and which functions would be done in which way. The result, the Navy argues, is a "best-of-breed" design within the SYSCOM environment.

It is important to note that the plan from 2004 was to shut down legacy systems as the Navy ERP went live. This action forced future Navy ERP use and thus may have increased user participation in the acquisition process. It reduced cost by eliminating functionally redundant systems.

Almost immediately after the Navy ERP baseline was established (August 2004), the program was buffeted by exogenous turbulence in the form of the 2005 round of BRAC. Less important were the details of that recommendation (which went to Congress for ratification in late 2005) than the Navy's decision to restructure its entire maintenance activity as a result.

Cost History

Technically, the Navy ERP program has breached Nunn-McCurdy limits (assuming such limits were meant to be applied to a Major Automatic Information System [MAIS] program). The program acquisition costs were significantly more than estimated in August 2004 (the date of its first baseline), the roll-out of the first increment went live a year or two later than planned,[4] and the capabilities of the current program of record are less inclusive than those originally promised in the baseline. Yet closer inspection reveals that the program has not experienced perpetual turbulence. Instead, estimates of cost and schedule have stabilized in a predictable manner since a program re-baseline in December 2006.

Table 3.2 illustrates the estimated program cost (in constant 2004 dollars) at four time points: August 2004 (the baseline), December 2006 (the re-baseline), late 2008, and late 2010. Costs rose 23 percent between the baseline and the re-baseline; they then fell 7 percent through the end of 2008 (as a result of reduced scoping decisions) and rose 3 percent as of September 30, 2010.

Of note, almost all of the estimate fluctuation occurs within the acquisition (RDT&E, procurement, acquisition operations and maintenance [O&M], and working capital fund-capital budget and operating budget) line item, even though these operations and support (O&S) costs[5] represent over half of the total. Table 3.3 compares the changes in the two from one period to another. The RDT&E account, at least initially, had even larger fluctuations, almost doubling between the baseline and the re-baseline.

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[4] The go-live date for every SYSCOM was staggered so that each one went live in a different fiscal year. Furthermore, within SYSCOMs, certain functions went live at different times. Hence the one-to-two estimate applies over the range of functions.

[5] Life cycle cost estimates include ten years past the date of full operational capability. This definition has remained consistent throughout the life of the Navy ERP thus far.

Table 3.2
Navy ERP Costs (millions of constant 2004 dollars)

	August 2004	December 2006	December 2008	September 2010
RDT&E	145.1	287.0	297.1	295.7
Procurement	75.4	61.0	61.5	62.1
Acquisition O&M	317.9	462.0	310.9	332.4
Working capital fund—capital	88.6	12.0	12.5	17.0
Working capital fund—operating budget		168.0	160.2	217.9
O&S	1,005.9	1,024.0	1,028.4	1,002.9
Total	1,632.9	2,014.0	1,870.6	1,928.0
% change		23.3	–7.1	3

Table 3.3
Navy ERP Costs and Percentage Change (millions of constant 2004 dollars)

	August 2004	December 2006	December 2008	September 2010
Acquisition	627.0	990.0	842.2	925.1
% change		+ 58	– 15	+ 10
O&S	1,005.9	1,024.0	1,028.4	1,002.9
% change		+ 2	+ 0.5	– 2.5

Some of these differences in cost increases over time may well be a function of cost allocation decisions by the Navy as program execution progressed. Some of the cost allocation methodology, in turn, is subsumed in the release changes reflected in Table 3.4 and the attending sources of financing for O&S. There is no clear record of these adjustments.

Thus, this root cause analysis focuses on internal program misconceptions and external shocks that resulted in initial estimation error. These dual phenomena—the cost estimate increase and schedule slippage that occurred between 2004 and 2006—coupled with the relative stability of the program since then and the fact that the various SYSCOMs have, in fact, gone live are what are to be explained.

Table 3.4
Go-Live Dates for Release 1.0 at Navy's SYSCOMs

	As of August 2004	As of December 2006	As of September 2010
NAVAIR		FY 08	FY 08
NAVSUP		FY 09 (2nd quarter)	FY 09
SPAWAR		FY 08 (3rd quarter)	FY 10
NAVSEA		FY 10 (2nd quarter)	FY 11

Program Changes

The Navy's decision to shift from intermediate maintenance activities to regional maintenance activities was profound, and as a result, unsettled the design and characteristics of the entire business process of the maintenance activity. In 2004, the Navy ERP program had planned an end-to-end system that would integrate maintenance into finance and supply. The plan (blueprint in ERP parlance) predicated intermediate-level maintenance as the first release. Yet the maintenance activities themselves were no longer stable. Although the Navy ERP program office maintained risk mitigation contingency plans that included schedule delays resulting from external program events,[6] the plans did not include contingencies for institutional organizational changes. The Navy ERP program office recognized the need for substantial blueprint revisions to accommodate the new organization of the Navy's maintenance activities. Unfortunately for planners, the Navy's maintenance architecture did not converge quickly enough to permit a solid, modified blueprint. The latter effort therefore took a considerable amount of time (a year or more) during which the meter was running, so to speak. This activity was reflected in the doubling of RDT&E expenditures between the original baseline and the new baseline generated in December 2006.

Table 3.5 reflects the effect of these changes, over time, in the standard PARCA root cause narrative methodology.

Cost Increases

Although the blueprint revision was expensive, it does not appear to account for the entire $400 million difference in cost estimates between the first and second baseline. The scope of the Navy ERP program after the second baseline was no greater than it was after the first baseline; in fact, it was putatively smaller. Thus, the most logical inference is that the Navy ERP program office took the opportunity presented to them by BRAC to offer a new baseline that incorporated lessons learned regarding the

[6] Risk mitigation planning concepts are discussed briefly in the 2004 Navy ERP ORD. RAND has not seen more detailed plans. Note that the Navy ERP ORD source of this information is likely not available to the public.

Table 3.5
PARCA Root Cause Narrative for the Navy ERP

	Year from MS B and Fiscal Year						
	B 2004	**+1 2005**	**+2 2006**	**+3 2007**	**+4 2008**	**+5 2009**	**+6 2010**
Baseline issues							
Unrealistic estimates for cost or schedule	X		X				
Immature technology; excessive manufacturing, integration risk							
Unrealistic performance expectations	X						
Execution issues							
Changes in procurement quantity			X			X	
Inadequate funding/ funding instability							
Unanticipated design, engineering, manufacturing, or technical issues							
Poor performance of government or contract personnel							
Unanticipated exogenous business practice changes		X	X				

cost of the Navy ERP. In other words, had the BRAC never occurred, the Navy ERP would have likely overrun its initial cost estimate, although, almost certainly, by less than $400 million.

The second baseline was generated in December 2006 prefatory to the Milestone C decision of September 2007. In the re-baselined version, the Navy ERP program office moved finance to the head of the capability release queue (release 1.0), followed by supply (release 1.1) and maintenance (release 1.2). This reorientation reflected the low confidence the program had that the architecture of the Navy's maintenance activities would stabilize quickly. This reorientation also included back-shop revisions as the scope of the finance release was broadened to include some of the work necessary for whichever capability came first, initially planned for the maintenance release.

Additionally, the Navy's ERP program office altered the original release concept to include a spiral approach by planning to release capabilities in phases. It further

divided the releases to the user groups. In this way, even as capability was portioned according to releases (maintenance, finance, then supply), each release had a different go-live date for each SYSCOM, often a full year apart.

As it became clear that the maintenance activity would not stabilize sufficiently to allow inclusion in the Navy ERP whose full development decision was planned for March 2011, the ERP program office dropped maintenance entirely from the program of record in late 2008, with corresponding decreases in the cost of the Navy ERP. However, program managers were careful to build in hooks from the finance and supply activities to some future maintenance activity. This way, if and when the latter did stabilize, the Navy ERP, by then well established, could interface with some future maintenance component of the ERP without significant revisions in the overall blueprint or in the configuration of the rest of the Navy ERP.

Schedule Delays

The first and major schedule slippage was likely associated with the 2005 BRAC-related disruption when the program essentially remained static for about a year. The original IOC estimate for the ERP program (or as it was known then, the ERP Convergence program) was the first quarter of FY 2007 for release 1.0 that was originally going to be maintenance. Such plans did not distinguish between SYSCOMs. The actual IOC was a year later, for just one SYSCOM (NAVAIR) and involved a redefined release 1.0 of finance. One way to understand the slippage is that the earliest module to was not implemented but that subsequent modules reached their earliest IOC as scheduled but not for the whole Navy; the other SYSCOMs had staggered and later IOCs.

Even after costs stabilized following re-baseline, there was continued, albeit minor slippage in schedules after that point. Several explanations for this can be offered. As noted, one reason is that the program office concluded that staggered go-live dates for each of the four SYSCOMs would be easier to manage than having two or more SYSCOMs go live at roughly the same time. Two, closely related, is the realization that ERP programs that have a profound effect on financial accounting should go live as the fiscal year begins rather than mid-year. Three, more subtle but indicative of the difference between an information technology acquisition and an ERP acquisition, the program office was concerned that one or more SYSCOMs were not ready to receive their ERP. The mismatch, it was feared, would wreck the processes that the ERP was trying to improve; customers did not have the choice of putting the ERP program aside until they were ready; the delivery of the program meant that legacy systems would be turned off and new business processes would begin. By contrast, the schedule for delivery of an air platform MDAP would not be so sensitive to user readiness; were one to deliver a jet before users were ready, the worst that could happen was that it would not be used very intensively in its first few months at the base.

RAND's Assessment of Future Navy ERP Program Risk

At this juncture, the Navy's ERP can be said to be a qualified technical success.[7] It has been implemented at three SYSCOMs. The two we visited can document the advantages they have gained so far. NAVAIR, for instance, has compiled a set of indicators for this purpose: e.g., timesheet compliance, contract obligation efficiency, late vendor payments, pay acceptance, unrecorded expenditures, unpaid balances, travel orders completed, and others. Most of them are going in the right direction, and some of them have exceeded objectives. NAVSUP, so far, has found a half-billion dollar's worth of cost savings, divided equally between reduced inventories (because NAVSUP has better global visibility into where its inventory sits and can detect items in oversupply worldwide) and lower information system maintenance costs. Indeed, the Navy was able to turn off over a hundred legacy systems when its ERP came online. And all this does not include the harder-to-quantify benefits of fewer administrative errors, the ability of personnel to shift from one job to another without having to learn a new system, the transition of the SYSCOMs from transaction commands to analytic commands, or better management decisionmaking.

Nevertheless, there is still a fair amount of optimization and fine-tuning that has yet to be completed. Unmatched disbursements, for instance, still exist within the current ERP, and the cross-functional value to the Navy (rather than to individual SYSCOMs) has yet to be documented. Tensions persist between the various SYSCOMs, which want to optimize the ERP to their unique issues, and the overall Navy, which wants conformance to its enterprise model. Although today's financials and audits are cleaner than they used to be, they are not clean in the absolute sense and may never be, given both the tendency of financial accounting to lag changes in financial policy and the interrelationships with Department of Treasury systems and processes.

What Went Right?

Although the Navy ERP program did not meet initial cost and schedule estimates, a re-baseline after two years proved accurate enough to predict internal milestones and to allow users to report satisfaction with the delivery of the program.

Several factors—many of which were common to experiences in the private sector successes but others unique to the Navy process—may have contributed to relative program success.

First, the pilot projects served as a de facto spiral acquisition approach for Navy ERP implementation. Granted, they were not cheap and, with the partial exception of NAVAIR's, not an insignificant part of the enduring Navy ERP program infra-

[7] RAND's analytic conclusion contrasts with GAO's conclusions of the Navy ERP program presented in reports published by GAO in 2005, 2008, 2009, and 2010. RAND used these reports to orient its research and ensure that work was not repeated unnecessarily.

structure. Yet they did give the SYSCOMs experience using an ERP and helped them understand many of their current business processes. They solved some data conformance and business process issues. They also provided a sense of what changes would have to be made to accommodate the transitions from local legacy management and information systems to integrated ERP systems.

Second, cost-plus contracting allowed the government to subsume part of the risk associated with altering its own business practices because of the cost-plus nature of the contract.[8] The program office is convinced that a contract vehicle that shared the cost risk between the government and the contractor was necessary for getting the latter's full cooperation on a project for which the government had little a priori expertise. This fostered an honest give-and-take between the contractor and the Navy essential to understanding the Navy's business processes and how they might have to change to accommodate an ERP.

Third, the determination to minimize the customization of the SAP solution decreased certain types of technological risks to cost and schedule. NAVSUP learned from the Defense Logistics Agency experience with its own business systems implementation that less customization had several major advantages. The resulting software would be less expensive, likely have fewer bugs, place the onus of software upgrades on the software provider, and better align business processes with commercial best practices. Since the commercial software had to be pre-approved and tested, reliance on it could help ensure a speedier program implementation. Failure to sharply scrutinize requests for customization might allow users to believe that they could maintain their old (and often incompatible) business practices, and refusal to allow many changes was a forcing function for standardization. NAVSUP authorities boast that only 2 percent of all Navy transactions required departing from the standard SAP transaction set (NAVSUP's own departure rate was well below 2 percent).

Fourth, the interactive governance of ERP allowed those who implemented it to develop a sense of staging as the program progressed. Not only were they careful not to break business processes in the course of implementation, but they also distinguished between financial systems (where a "big-bang" switchover was appropriate) and material management (where such a switchover was not necessary). NAVSUP staged the latter in several tranches, with each tranche mixing in hard and easy problems rather than pushing the harder problems into the last tranche. They also established 20 stabilization criteria (a quarter of which were deemed major) by which to evaluate the transition.

Fifth is that the Navy and its SYSCOMs' leadership showed a consistent high-level interest in the program. This support proved critical for maintaining the (as described) painful business re-engineering that seemingly suboptimized command processes. The NAVSUP commander held weekly meetings on the organization's implementation

8 The contract was a combination of cost-plus-fixed-fee and cost-plus-award-fee.

process and managed to appear in person at most of them (he participated in the rest via telephone or video teleconference). Vice Admiral Lockhard, the NAVAIR commander (when the first pilot, entitled SIGMA, was initiated), was also a strong proponent and contributed key personnel to the ranks of Navy ERP management.

Concluding Policy Lessons

The rationale for applying a Nunn-McCurdy test to an ERP acquisition program is, at first glance, compelling. These are expensive programs, a larger percentage of which fail, often spectacularly compared to MDAPs. Large software programs almost always cost more than planned, finish later than scheduled, and deliver less than promised. Several colossal government system acquisition failures have become virtual legends: the Federal Bureau of Investigation's Virtual Case File system, the Federal Aviation Administration (FAA) Air Traffic Control system upgrade, New Jersey's Department of Motor Vehicles system, and, within DoD, the Defense Integrated Military Human Resources System.[9] Typically, when such systems do fail, very little is recoverable, other than hard-won wisdom. They also demonstrate a high rate of failure in the commercial world.[10] ERP failures were not uncommon in the private sector efforts also.

At second glance, the case is less obvious. The basic theory behind Nunn-McCurdy is that the inability of a program to control its costs and keep on a schedule is a sure indicator of trouble. Such programs often appear fine in reporting metrics until the point comes when they are not. Rapid intervention is then required to determine whether such breaches should be mitigated by program changes, or, instead, whether such a breach is the first of many signs that a program simply cannot perform. Either way, breaches generally indicate that the program needs major scope changes or its costs will continue to escalate out of control. This is an important consideration for hardware MDAPs because the bulk of all costs occur during the production rather than the development phase. By contrast, ERP-like MAIS programs inherently complete an abridged acquisition process, where software development and software production occur concurrently, yielding a deployable product. As such, early cost increases may be the only cost increases if other factors such as executive leadership support, contractor compliance, and strong governance exist.

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[9] For the FBI's Virtual Case File system see Harry Goldstein, "Who Killed the Virtual Case File?" *IEEE Spectrum,* Vol. 42, No. 9, September 2005, pp. 24–35. For the FAA's air traffic control system, see Government Accountability Office, *Air Traffic Control: Immature Software Acquisition Processes Increase FAA System Acquisition Risks,* Washington D.C., GAO/AIMD-97-47, March 1997. For the Defense Integrated Military Human Resources System, see Kevin McCaney, "Readers Offer Stuffing for IT Turkey," *Federal Computer Week,* December 1, 2009. For the New Jersey Department of Motor Vehicles System, see Robert Glass, *Software Runaways: Monumental Software Disasters,* Upper Saddle River, N.J.: Prentice Hall, 1997.

[10] Chris Kanaracus, "Biggest Enterprise Resource Planning Disasters of 2010," *PCWorld*, December 17, 2010.

Another problem with extending the Nunn-McCurdy criterion is the unavoidable ambiguity associated with counting "eaches" in a business process system—a far smaller concern when tracking cost growth in hardware programs. The Navy ERP, for instance, covers a large number of people, but most of them use the Navy ERP only for time-and-attendance worksheets. The bulk of the Navy ERP costs, however, arise from bringing asset and financial management programs within the logistics community to a smaller population of power users. Each class of power users, in turn, employs different levels of functionality from within the ERP program. This is more than an accounting quibble. The Navy ERP has been deemed sufficiently successful that moves are under way to extend it to shipboard applications and other functions outside logistics channels. But the Navy faces the difficult choice between calling an extension a new program start, with all the associated paperwork thereby implied, or simply extending the Navy ERP, which creates ostensible program growth according to Nunn-McCurdy criteria, making a largely successful program appear to be a failure.

Consider, therefore, what might have resulted from a straightforward application of the Nunn-McCurdy test to the Navy ERP. The breach, as such, would have arisen in late 2006. The process associated with the breach would have asked whether the Navy ERP was under control or, instead, destined to explode. Perhaps the program managers could have successfully argued that the program's problems were created by exogenous factors (although some early-course estimate correction was also involved). In retrospect, however, it was clear that the Navy ERP was not headed toward disaster; the program has been quite stable since then. By 2007, in fact, much of the most difficult work and "lessons learned" had been incorporated into the new baseline as the first release was about to go live at NAVAIR.

More broadly, ERP programs are not stand-alone procurements in the same sense that a jet fighter acquisition or even a network defense project is. The major share of the cost is associated with understanding and adapting business processes to the business model built into the software. As noted, one cannot understand the cost of an ERP without understanding the enterprise that the ERP is designed to re-engineer, but understanding that enterprise constitutes a major share of the overall ERP costs. As for alternative cost-estimating techniques, notably, parametric cost estimation (e.g., in terms of reports, interfaces, conversions, and extensions objects), accuracy is hostage to the great variance in legacy business processes from one organization to another. Finally, the number of people in the Navy who knew enough to establish requirements was quite limited, and such individuals were often engaged elsewhere. The Navy ERP program office attempted to implement a clearly defined "implementation cost-sharing scheme" between the SYSCOMs and the program office to avert some of the moral hazard endemic when offering money from one organization to another for business system use. It helped but hardly addressed the root dilemma.

CHAPTER FOUR

Examination of Program Complexity

A primary emphasis in the performance evaluation of an MDAP is on cost. In part this is because unit cost growth is the primary trigger for a Nunn-McCurdy breach. This is clearly demonstrated by the organization of the "speeding ticket" displayed in Table 2.1. However, many underlying factors contribute to program performance and risk of failure. During the RAND root cause analysis of the six programs assigned to date for review, we observed a number of approaches used to characterize the nature of program risk and progress that were applicable DoD-wide. These various approaches include those used to create the Program Deviation Report that describes the program's cost growth, the SAR, as well as approaches taken by other organizations such as in the GAO Defense Acquisitions Assessments of Selected Weapons Programs serial reports.

Although these approaches may be useful in providing a rich opportunity for observation, in many instances, indications that problems existed were not sufficiently obvious to be used in a timely manner by decisionmakers. However, the most important details are not often presented in an easy-to-use form. Decisionmakers need tools to navigate this mass of bibliographic data, but even more important is the experiment designed to help a decisionmaker initially chart a course through the data. Well-designed exercises could help make more obvious the critical components that pose the greatest risk of program failure. With this information, a more informed decisionmaker might make more timely inquiries into the performance of those critical features before problems mount.

When unaddressed, problems originating from the most critical features of a program threaten the life cycle of the program. To make the information that DoD decisionmakers need more timely and actionable, decisionmakers should adopt a framework for thinking about the program features ahead of attempting a deep dive into the data looking for problems. An initial conceptual framework would allow a decisionmaker to quickly determine what is most critical, complex, or least understood of the list of program features. Root cause analysis as an element of Nunn-McCurdy breaches focuses on program acquisition, but the process used by analysts to structure review criteria could also be used by decisionmakers to identify total ownership cost challenges and critical points of risk in the complex programs.

This chapter discusses methods to identify critical features to help decisionmakers focus their effort to uproot various program risks through a selective screening experiment.[1] In our discussion of Excalibur in this report, we review critical features of that program through monthly technical risk reports and conclude that early warning signs were available that could have signaled the program's trajectory toward failure. Our analysis and the findings presented in our Nunn-McCurdy Breach Program Reports suggest that it may be possible to develop a framework that would enable a different review of programs to enhance our understanding of risk. This chapter provides an exercise designed to help decisionmakers develop the type of initiating hypotheses that are necessary to chart a path through the bibliographic data, leading the decisionmaker to the critical features with the greatest risk to the program. The exercise described here is an approach the authors felt most useful; clearly, others may be designed.

Measures of Merit

The exercise described in this chapter incorporates two of the many concepts that root cause analysts use to develop an initiating hypothesis about why a program has breached. These critical concepts include the program system complexity and the level of detail available about various technical components. Early in the root cause analysis, the review team assembles a time line of the program's relevant history. This process is discussed in detail in a companion forthcoming report.[2] At this early stage, the review team identifies the system failures, schedule delays, and other incremental challenges that led to the program failure by tracing through the detailed log and bibliographic data. The components that are reviewed to develop the time line often are the most complex features of a program. In the past, the most important details about these complex program components have been uncovered in the least visible places—buried in briefing charts, hidden in technical log files, and only briefly referred to in monthly engineering reports. The components that the review team chooses to highlight in the program's time line are often the most complex and least visible, because these often contain the most risk to the program.

We propose that decisionmakers use a "selective screening of critical components" process to identify the features of most risk to the program, similar to the process of identifying items for a review team to track along the program's time line. To identify the components with the most potential program risk, we developed a methodology for the exercise based on the root cause analysis process to relate "measures of merit"—the

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1 The examples in this chapter cover many of the other programs detailed in this and previous publications in the RAND RCA series. One notable exception, the Navy ERP, was not included because, as a software system aimed at standardizing Navy business operations, the program is not an MDAP.

2 Irv Blickstein et al., *Methodologies for Analyzing the Root Causes of Nunn-McCurdy Breaches,* Santa Monica, Calif.: RAND Corporation, TR-1248-OSD, forthcoming.

standard measures used by a variety of *Jane's* publications[3] to describe programs—to the complexity and level of data detail available for specific program features. What we define as a measure of merit is broadly a set of technical components that contribute to a measurable process. As an example of a measure of merit, the Longbow Apache AD-64A (AB3) power plant design includes two General Electric T700-GE-701C turboshafts, which are each rated at 1,409 kW for 10 minutes and 1,342 kW for 30 minutes. The rating category for this power plant design feature is a measure of merit called the "maximum continuous drive" for the platform. Other helicopters may be capable of achieving even greater levels of sustained performance in kilowatts, but all will incorporate the maximum continuous drive measure of merit. Platforms other than helicopters also use this measure of merit, such as the Joint Strike Fighter and the *Zumwalt*-class Destroyer, to describe the power plant features. There are considerable differences between the technological complexity of the power plant design required for a destroyer and that of a jet fighter, but the common measure of merit defines a set of similar components. By this definition, a measure of merit includes specific technical components as well as systems of components used to generate a particular level of performance, such as the maximum continuous drive. This broad definition was adopted to frame the decisionmaker's thinking about the program as an amalgamation of processes as opposed to a less relevant list of parts.

We crafted a graphical display to help the decisionmaker identify the most important features through the selective screening process. Figure 4.1 is an aggregate image of the Longbow Apache measures of merit as ranked for level of system complexity and level of detail required to access each feature's underlying data (the level of detail increases with system complexity). The specific ranking levels for each axis are discussed later in this chapter. The bubble chart depicts the frequency of measures of merit at various coordinates on the matrix. Larger bubbles indicate a larger count of measures of merit at the particular coordinate than do smaller bubbles. The different bubble colors simply differentiate one coordinate on the matrix from another. Generally, measures of merit that rank in the upper right-hand corner of the chart—near the upper bound of each complexity and level of detail axis—contain more risk than others. In a root cause analysis, the reviewers would pay extra attention to the history of these complex programs that have less available information.

The purpose of this exercise is to help orient a decisionmaker toward components and features of a program that contain the most risk before a breach occurs. As a result of this exercise, decisionmakers will be more able to focus their ongoing analytic efforts on the specific critical features that are necessary to a program's success. The graphical display or matrix that is constructed as a part of this process can be used to identify components that are of the greatest risk to a program. As described, this is done by

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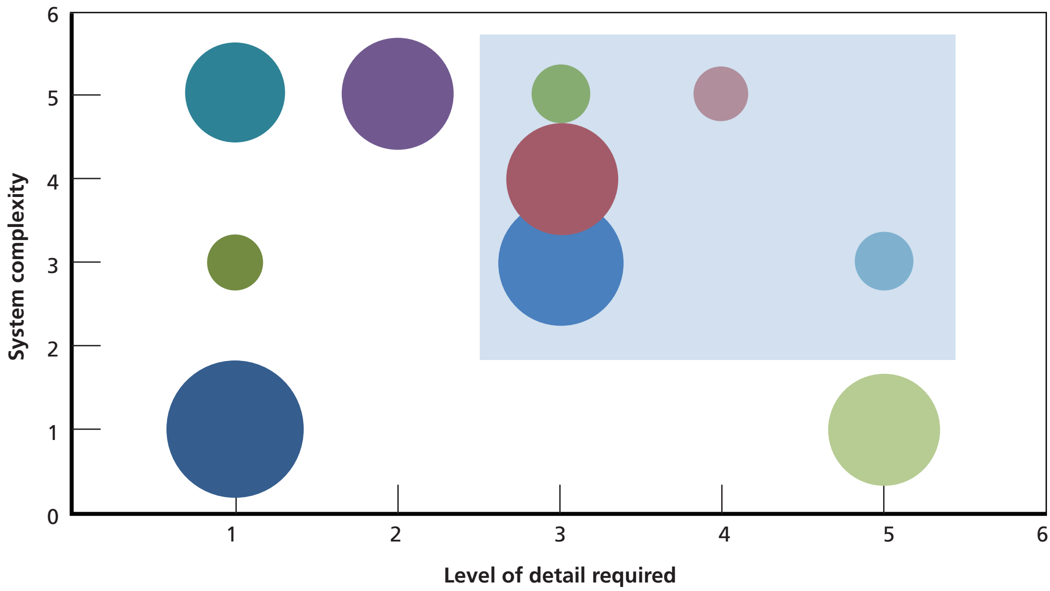
[3] We initially assembled a list of measures of merit used in *Jane's All the World's Aircraft, Jane's Ammunition Handbook, Jane's Space Systems and Industry,* and *Jane's Fighting Ships* to describe the different programs.

Figure 4.1
Longbow Apache Nominal Example



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relating the measures of merit for the program to specific levels of technological complexity and levels of detail. The most important measures of merit to consider are those that are both highly complex and the least visible (those in the shaded blue square in Figure 4.1 that are closer to the upper right-hand corner of the display). For a detailed description of the Longbow Apache risk as identified by the matrix, see Figure 4.5 and the associated discussion later in this chapter.

As for the Longbow Apache and the other programs assigned to date, we coded each measure of merit for both complexity and level-of-detail scales. The results were an alignment of the rating scales to a coordinate plane in a two-dimensional 5 × 5 matrix. This allows the assignment of every *Jane's*-based measurement to a coordinate, as seen in Figure 4.1. With this tool, the decisionmaker or reviewing analyst can evaluate the frequency of components at various regions of the resultant "complexity-detail matrix" to get a better view of the measures of merit that contain the program features with the most potential risk. Construction of this matrix is an important aspect of the selective screening thought process. Table 4.2, below, depicts the rating scales used to create the matrix. The list of components that are clustered around specific regions of the chart, such as at the upper right-hand corner, should be evaluated with greater scrutiny. As an example of the codings and the specific measures of merit, Table 4.1 displays the data associated with the Longbow Apache gathered from *Jane's All the World's Aircraft*.

Table 4.1
Longbow Apache Measures of Merit

Design Category	Measures of Merit	Level of Detail Required	System Complexity
Armament	Areas	1	1
Armament	Maximum ammunition load	1	1
Avionics	Flight	1	1
Capacity	Crew	1	1
Structure	Dimensions, external	1	1
Structure	Payload	1	1
Armament	Weights and loadings	1	3
Armament	Accuracy	1	5
Performance	Range	1	5
Performance	Speed	1	5
Flying controls	Hover hold	2	5
Power plant	Crash/impact resistance	2	5
Power plant	Low speed stability	2	5
Avionics	Mission	3	3
Avionics	Radar	3	3
Capacity	Survivability	3	3
Structure	Crash/impact resistance	3	3
Systems	Crash/impact resistance	3	3
Avionics	Communications	3	4
Avionics	Instrumentation	3	4
Flying controls	Fuselage attitude	3	4
Power plant	Continuous maximum drive	3	4
Avionics	Self-defense	3	5
Avionics	Target acquisition	4	5
Landing gear	Energy absorption	5	1
Power plant	Power management	5	1
Systems	De-icing	5	1
Systems	Power management	5	1
Structure	Rotor noise reduction	5	3

In Table 4.2, system "complexity" is designed as an indication of potential design, engineering, and integration difficulty related to a component. The rating scale of complexity range, from 1 to 5 or "straightforward" to "technologically unproven." The definition of complexity used here is not engineering, operational, or even programatic complexity but rather a broad level of complexity that is developed through the exercise. For example, many aspects of the Joint Strike Fighter were technologically unproven—the highest order of complexity; these components include the high-rate transonic turning flight controls, which contributed to system design challenges cited by previous RAND research.[4] At the other end of the complexity spectrum was management of the landing gear for the Joint Strike Fighter. Landing gear represents a more straightforward, possibly off-the-shelf component with well-documented technology that would have contributed very little to the overall technical risk.

Table 4.2 also defines level of detail or visibility as an indicator of the amount of effort required to attain suitable documentation on the component of interest.[5] This axis captures the extent to which information about the program is "pushed" to the decisionmaker. From the experience of collecting the bibliographic data, we constructed a scale that ranges from 1 to 5, or "advertised," meaning that documentation is prevalent and pushed to decisionmakers, and, at the other end, the information is "buried," in which case the data are available only in obscure locations that are also difficult to access. Material that is buried includes those items in a programs bibliographic data that we came across on site visits or found almost by accident. Support from PARCA, the program office, and other gatekeeper organizations is necessary to access and to even learn about the less visible data that seem to belong in the buried category, whereas "advertised" material is often available to the general public. See Figure 4.2 for

Table 4.2
Complexity-Detail Matrix Ratings

Value	Level of Detail Required	System Complexity
1	Advertised	Straightforward
2	Available	Integrate existing
3	Accessible	Innovative technique
4	Limited	Complex behavior
5	Buried	Technologically unproven

[4] See Blickstein et al., 2011, p. 90ff, for RAND's root cause analysis of the Joint Strike Fighter.

[5] The challenges associated with gaining access to the data required for a root cause analysis is discussed in Chapter Four as well as in Appendix G of Blickstein et al., forthcoming.

Figure 4.2
Snapshot of a Comparison of Program Measurement Systems

Each program is characterized by a sequence of relevant units of measure. Precision, speed, and range are important performance measures for the Excalibur, but not for the WGS.

The performance categories used to describe the Excalibur are similar to those used for the Longbow Apache and the Joint Strike Fighter....

However, the power plant and structure categories are very different.

Row Labels	Longbow Apache	Excalibur	Joint Strike Fighter	Wideband Global Satellite	*Zumwalt*-class Destroyer	
Performance	2	3	2		2	4
Precision		1				1
Range	1	1	1		1	4
Speed	1	1	1		1	4
Power Plant	4		3	2	2	4
Continuous maximum drive	1		1		1	3
Crash/impact resistance	1					1
Downward thrust deflection			1			1
Low speed stability	1		1			2
Power management	1			1	1	3
Solar arrays				1		1
Structure	4	1	2	1	9	5
Beam					1	1
Crash/impact resistance	1				1	2
Dimensions, External	1		1			2

NOTE: The bottom of the figure has been cut off for display purposes, and some numbers do not appear on the chart.
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the full rating scales used to classify the list of measures of merit that was assembled from *Jane's* publications.

Classification of the measures of merit was based on RAND experience and familiarity with the collection process and the intricacies of these various systems. We reviewed past work and consulted with several researchers who had been deeply engaged in the initial root cause analysis of each platform to complete the exercise and construct the specific ratings described in this chapter.

Comparing Measures of Merit Across Programs

In broad terms, all programs have measures of merit, such as those used in *Jane's* publications, and some of these measures are common and some, such as those that describe the Excalibur, are more system-specific than those found in major platform programs. For example, the power plant "continuous maximum drive" and "low speed stability" of the Longbow Apache are measures of merit common with those of the Joint Strike Fighter. Similarly, performance is measured in terms of range and speed for the Longbow Apache, Joint Strike Fighter, Excalibur, and the DDG-1000. The performance of Excalibur, unlike the other programs, is also based on units of precision or accuracy. This additional unit is not surprising, as Excalibur was built, advertised, and is required to be precise so as to reduce collateral damage, particularly in urban environments.

Figure 4.2 provides a comparative display of power plant and structural measures of merit that address five of the MDAPs assigned to date to RAND for analysis.[6] The columns show the systems and the rows the components. The rows in boldface contain the sum of the subcategories. For example, the Longbow Apache has a "4" under power plant, which is the total of four subcategories: continuous maximum drive, crash impact/resistance, low speed stability, and power management. As the figure shows, the Joint Strike Fighter has similar systems, which would enable a comparison across systems.

Although similar measures of merit might be used to describe different programs, the calculations are based on integration of the specific characteristics of very different technologies. For example, structural "crash/impact resistance" means the amount of damage (by caliber round) that the airframe and fuel cells of the Longbow Apache can sustain. On the other hand, the same *Jane's*-listed measure for the DDG-1000 refers to the wide distribution of ballistic impact across the hull to reduce the risk of single-hit ship loss. The fuel cells and air frame designed for the Longbow Apache are relatively standard across the light attack helicopter industry; whereas, optimized for stealth, the DDG-1000 hull design is the result of more innovative engineering. In each case, the single measure of merit reflects different levels of system complexity. The difficulty in having measures that are useful and actionable is that if the category is homogenized enough, the meaning is lost.

Because of this need for a more tailored understanding of the measures of merit, RAND developed the selective screening exercise. A product of the exercise is the complexity-detail matrix addressed above (Table 4.2) and found in Figures 4.5 through 4.9, below, for each program assigned to date to depict the programs through the associated "complexity" and "level of detail" or visibility ratings. The complexity-detail matrix shows how frequently program components exhibit various levels of complexity and visibility through the use of larger and smaller bubbles. For better understanding, some of the bubbles in Figures 4.5 through 4.9 have the specific program component nomenclature indicated. This mechanism is an example of how existing data can help identify underlying complexities. Figures 4.3 and 4.4 depict the complexity and level of detail axis on the matrix, using the scales from Table 4.2. A greater explication of the axes and their use is discussed in the program-specific example matrices.

The program components that are more complex and also less visible carry much of the risk related to program failure. These critical features to a program can be identified by reviewing the components that are within specific coordinate clusters on the matrix. The following section provides specific program examples using the matrix. The approach followed is somewhat akin to the methodology used to analyze a quad

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[6] All measures used in the analysis in this chapter are entirely based on the most recent program descriptions from *Jane's All the World's Aircraft, Jane's Ammunition Handbook, Jane's Space Systems and Industry*, and *Jane's Fighting Ships.*

Figure 4.3
System Complexity Analysis

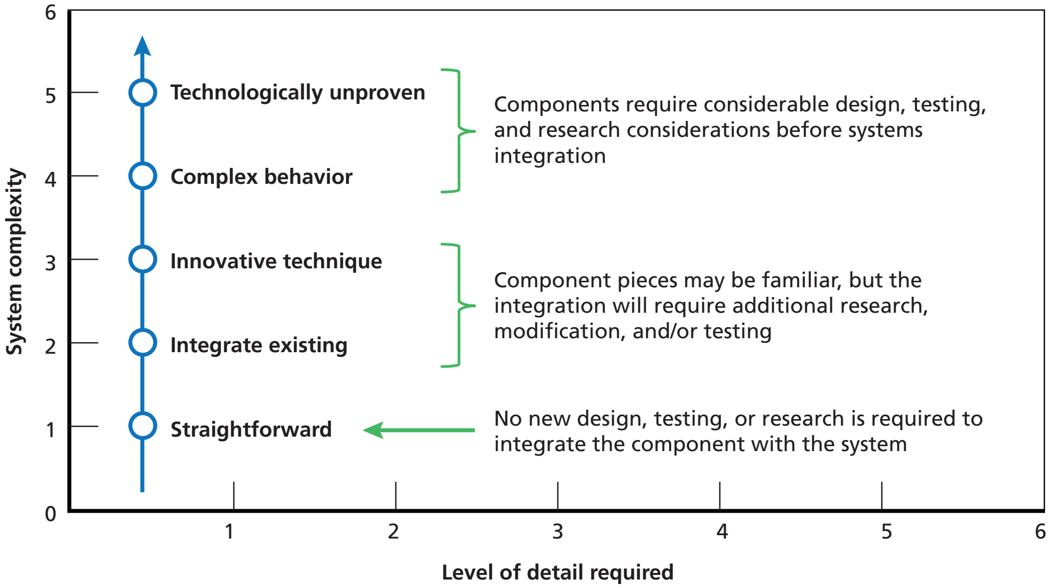

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Figure 4.4
Level of Detail Required Analysis

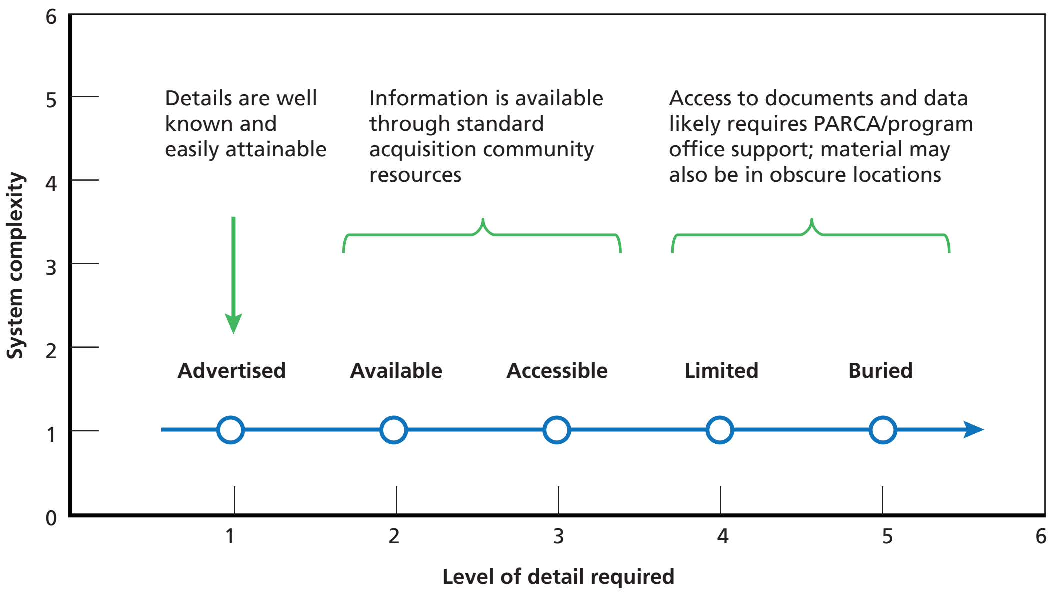

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chart in that the displays focus the observer on specific data points within particular regions of the depiction.

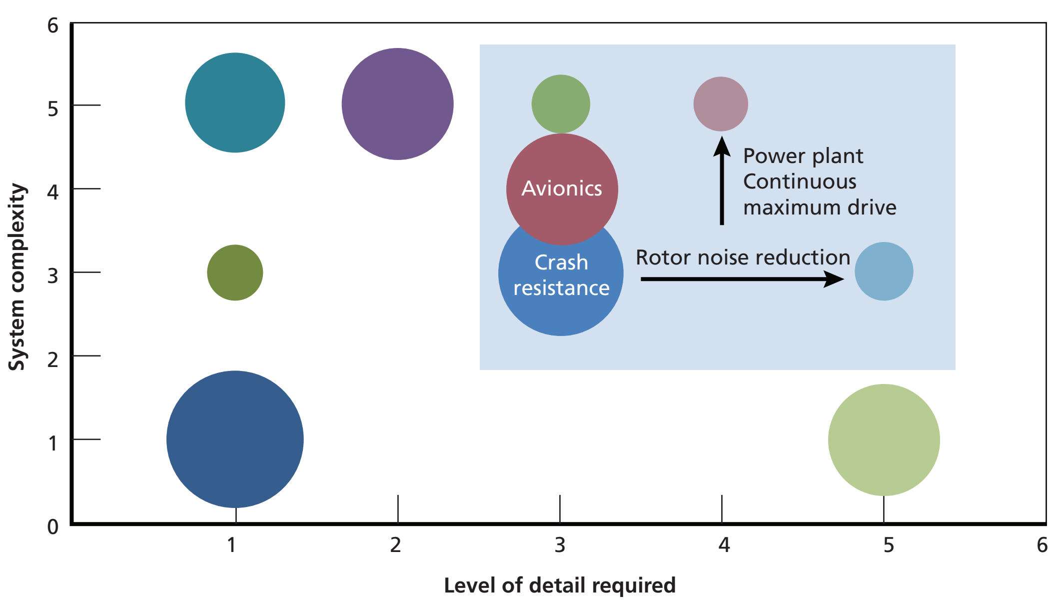
Program-Specific Examples for Using the Exercise for Complexity-Detail Matrix Through the Selective Screening of Critical Components

The following charts are based on several of the programs assigned to RAND to date. In each, the scales used on the horizontal and vertical axes are those for complexity and level of detail or visibility that are depicted in Figures 4.2, 4.3, and 4.4. The root cause analysis material for Excalibur is from the root cause analysis in this report, whereas the Longbow Apache, Joint Strike Fighter, DDG-1000, and Wideband Global Satellite are from the material generated for the associated root cause analyses detailed in Blickstein et al., 2011.

Longbow Apache

By Army accounts, the Longbow Apache incorporated 15 cutting-edge technologies; this magnitude of complexity introduced greater integration and development challenges to the program. Figure 4.5 depicts the Longbow Apache measures of merit on the matrix. The chart relates the various levels of complexity to level of detail or visibility of the underlying components. The feature clusters that are in the shaded blue

Figure 4.5
Longbow Apache



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square reflect those of the greatest potential risk because they are both complex and the information documenting the components are more buried than in other systems. The components within the blue shaded square region of the chart include the rotor noise reduction, continuous maximum drive of the power plant, and avionics and crash/survivability in the structure design. The RAND root cause analysis of the Longbow Apache revealed that the increase in costs associated with the rotor and the power plant drive system, which was documented at the development stage MS B, contributed to the Nunn-McCurdy breach.

Although not all of the components that fall within the blue shaded region contributed to the root cause of the breach, knowing the few critical features to follow is beneficial to the analyst.

F-35 Lightning II Joint Strike Fighter

For the F-35 Lightning II Joint Strike Fighter, the most complex systems were also difficult to integrate and led to delays. A paramount need for stealth in the new Joint Strike Fighter required an innovative flight avionics arrangement, a unique trapezoidal mid-wing configuration, and internal weapon bays. The need for stealth, with the design of more technologies inside the airframe, resulted in an excess of weight in the F-35B and F-35C variants that was difficult for the program to shed. Appropriate weight growth given the requirements was also not accounted for in the MS B baseline 2001 cost estimates, as these were based on legacy aircraft data. Redesigns to reduce weight contributed to, but were not the sole cause that increased the unit cost beyond the approved levels.

Information about the Joint Strike Fighter weight distribution and trimming challenges associated with the need for stealth was found in a PowerPoint presentation provided by the Lockheed Martin System Engineering Director on April 23, 2010. This information was considered "buried" on the level-of-detail scale as it was uncovered only while joining the PARCA office on a site visit to Lockheed Martin. So buried information can be well known; the weight problems were reported widely. Several of the slides prepared for the PARCA office by Lockheed Martin characterized the weight growth as a considerable barrier over a ten-year time line.[7] This information was difficult to acquire but became available through the support of the PARCA office.

Figure 4.6 captures the Joint Strike Fighter measures of merit as described by complexity and component visibility. The shaded region in the upper right-hand corner identifies components that exhibit both a high level of complexity and a low level of visibility. Examined further, the cluster includes components such as the flying controls for high-rate transonic flight, the thermal management system, and the various avionics and power plant systems. As described in the Joint Strike Fighter root cause

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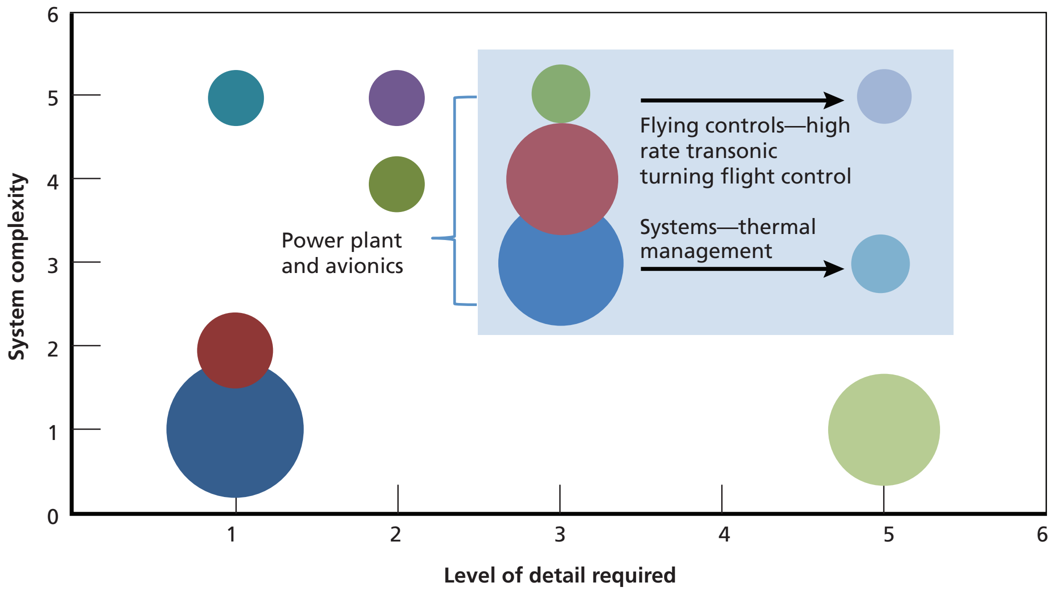
7 Paul Park, System Engineering Director, "PARCA Review: Air Vehicle, F-35 Lightning II," Lockheed Martin, PowerPoint reference file: "AVT_Park_Rev02.ppt," April 23, 2010.

Figure 4.6
Joint Strike Fighter



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analysis, the integration of these complex components into a stealth design resulted in an increase to the overall weight, which was not accounted for in the MS B baseline.

The underlying data associated with Figure 4.6 are depicted in Table 4.3.

Components in the shaded region of Figure 4.6 contributed to the Nunn-McCurdy breach because the process of designing these complex technologies into the stealth frame resulted in a rapid increase in overall platform weight. Knowing the list of components to focus on would lead the analyst toward overall underlying trends that contributed to risk in the program.

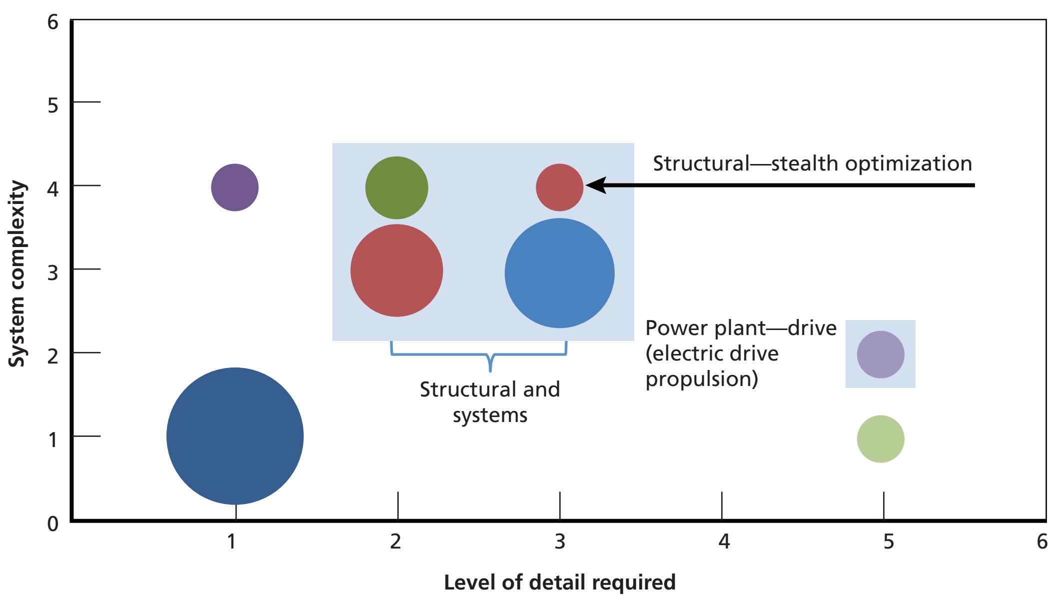
Zumwalt-Class Destroyer (DDG-1000)

Similar to the Joint Strike Fighter, the *Zumwalt*-class Destroyer (DDG-1000) is designed for stealth and integrates advanced technologies but in this case for long-range land attacks. Regardless of the design and integration challenges associated with complex systems, the RAND root cause analysis detailed in the PARCA I report (Blickstein et al., 2011) identified that the quantity change from ten to three ships was the main driver of the unit cost growth that resulted in the breach. More important, the RAND research found that another cause of the breach may have been an unrealistic assessment of the baseline at MS B. In the case of DDG-1000, Figure 4.7 could have been used by an analyst to identify the levels of complexity that differentiate the DDG-1000 from the DDG-51 before assessing the baseline cost.

Table 4.3
Joint Strike Fighter Measures of Merit

Design Category	Measures of Merit	Level of Detail Required	System Complexity
Armament	Length	1	1
Armament	Payload	1	1
Armament	Weight and loadings	1	2
Structure	Penetration	1	1
Flying controls	Lifting glide ratio	1	3
Flying controls	Stabilization	1	3
Performance	Precision	1	5
Performance	Range	1	5
Performance	Speed	1	5
Systems	Height of burst	2	3
Systems	Guidance	2	5
Systems	Launch control	3	2
Systems	Sensors	3	2

Figure 4.7
***Zumwalt*-Class Destroyer**



RAND *MG1171/2-4.7*

The DDG-51 is a multimission destroyer, designed for air defense and ocean-based operations, whereas the DDG-1000 is designed for operations in littoral areas and naval surface fire support. To support this fundamental difference in operational need, the DDG-1000 required the integration of several new technologies. The cost structure for the DDG-51 was used as a basis for the DDG-1000 initial pricing, although the two have very different platforms. The blue shaded region in Figure 4.7 captures several of the technologies that differentiated the DDG-1000 from the DDG-51. To accommodate the new technologies, the DDG-1000 is structurally larger and has more automation features allowing it to operate with fewer crewmembers (142 sailors compared with approximately 300 on the Navy's *Arleigh Burke*–class Destroyers [DDG-51] and *Ticonderoga*-class Cruisers [CG-47]). The blue shaded region in Figure 4.7 captures the increased draft and other structural differences as well as the integrated electric drive propulsion system and automation technologies.

These differences can also be viewed through the underlying data depicted in Table 4.4.

In the case of the DDG-1000, the analyst's early understanding of the technical complexities that contribute to risk in the system may have helped to better specify the baseline costs. This type of evaluation of the underlying features and critical components of a program is valuable not only in the root cause analysis but also in the general characterization of a program before it is at risk of failure.

Excalibur

The Excalibur projectile program was merged with the Trajectory Correctable Munitions program in 2002 to complement the Future Combat System NLOS Launch System (NLOS-LS) launch capability. The NLOS-LS was ultimately canceled in May 2010, and the Excalibur Nunn-McCurdy breach was announced in August 2010. The RAND root cause analysis in this report points to inaccurate initial estimates of cost and a change to the operational concept of the device as the primary causes, but the analysis also identified several long-term technology challenges. Similar to the DDG-1000, the design and development history of Excalibur suggests that earlier identification of the critical components and potential areas of risk could have helped to avert the major challenges that contributed to increased costs.

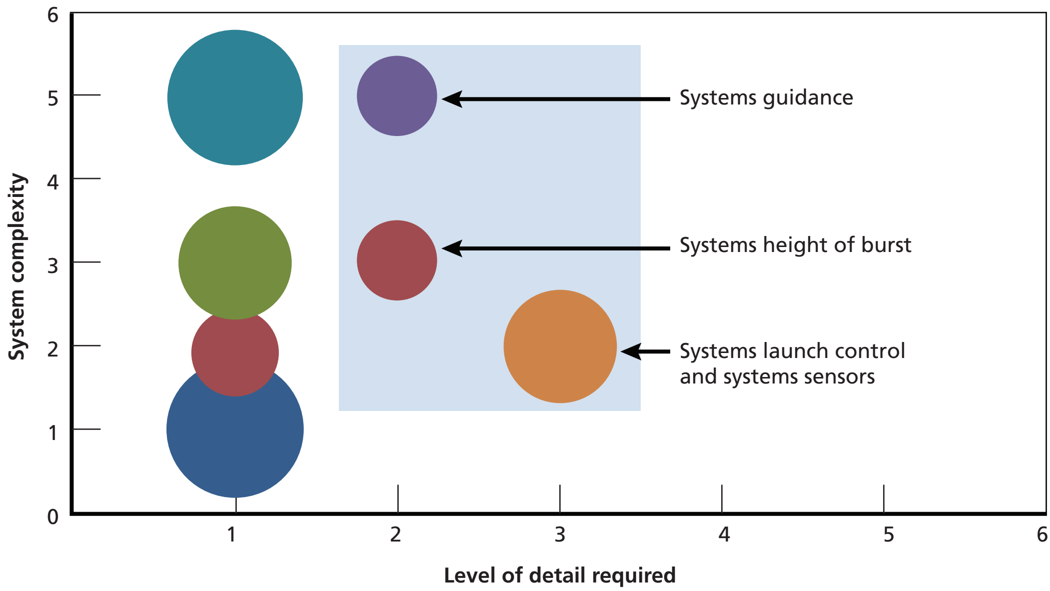
The shaded blue regions of Figure 4.8 capture the technologies that represented the most risk for the Excalibur system. Described in greater detail in Chapter Five of this report, these include the systems components for the height of burst, guidance, launch control, and sensors. These system components were necessary for the high level of precision required for Excalibur, but early failures in these systems led to long-term scheduling delays and previously unforeseen costs that contributed to the overall program risk.

The underlying data for Figure 4.8 are depicted in Table 4.5.

Table 4.4
***Zumwalt*-Class Destroyer Measures of Merit**

Design Category	Measures of Merit	Level of Detail Required	System Complexity
Armament	Guns	1	1
Armament	Missiles	1	1
Armament	Torpedoes	1	1
Capacity	Crew	1	1
Equipment	Decoys	1	1
Equipment	Unmanned aerial vehicles/helicopters	1	1
Performance	Range	1	1
Performance	Speed	1	1
Structure	Payload	1	1
Structure	Beam	1	4
Structure	Displacement	2	3
Structure	Draft	2	3
Structure	Length	2	3
Structure	Survivability	2	3
Structure	Crash/impact resistance	2	4
Structure	Stealth optimization	2	4
Systems	Radars: air/surface search	3	3
Systems	Radars: navigation	3	3
Systems	Radars: surface search	3	3
Systems	Sonars: active search	3	3
Systems	Sonars: attack search	3	3
Systems	Sonars: passive array	3	3
Power plant	Continuous maximum drive	3	4
Power plant	Power management	5	2
Structure	Power management	5	1

Figure 4.8
Excalibur



RAND *MG1171/2-4.8*

Table 4.5
Excalibur Projectile Measures of Merit

Design Category	Measures of Merit	Level of Detail Required	System Complexity
Armament	Length	1	1
Armament	Payload	1	1
Armament	Weight and loadings	1	2
Structure	Penetration	1	1
Flying controls	Lifting glide ratio	1	3
Flying controls	Stabilization	1	3
Performance	Precision	1	5
Performance	Range	1	5
Performance	Speed	1	5
Systems	Height of burst	2	3
Systems	Guidance	2	5
Systems	Launch control	3	2
Systems	Sensors	3	2

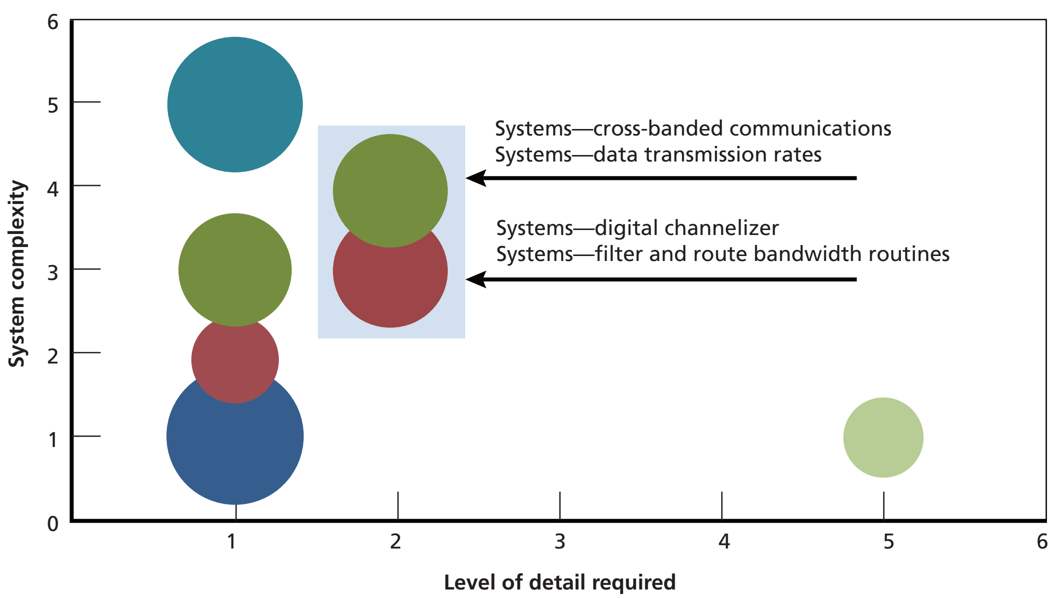
The information gained from analysis of the complexity and visibility of various components of the Excalibur would help the analyst identify the critical features that should be closely monitored during the design, development, integration, and production phases of the program. This example suggests that alternative views for these complex weapons programs are necessary to better understand the nature and potential sources of risk throughout the program's life cycle.

Wideband Global Satellite

Fast and clear communication between the battlefront, mission headquarters, and defense strategic commands is critical to deploying resources. Wideband Global Satellite is a component of the military's investment strategy to build the communications infrastructure for the future. Unlike other programs, the WGS cost structure placed more of the burden on the program engineering prime contractor, obligating Boeing to recoup development costs from the commercial market rather than fully supporting the overhead costs through funding from DoD.

Over time, the WGS evolved from a commercial platform with military features to an almost entirely military-purpose device. Identified by the RAND root cause analysis, a growing difference between the commercial and military variants of the WGS resulted in components that were maintained through successive designs to meet the military requirements that were no longer "commercial off-the-shelf." The commercial market took note of this evolution, and the commercial WGS ratings declined

Figure 4.9
Wideband Global Satellite



RAND *MG1171/2-4.9*

as a result. The WGS Nunn-McCurdy breach was caused by internal cost growth and external market conditions.

The shaded blue regions of Figure 4.9 identify several of the more technically complex features of the WGS. These include systems components such as the digital channelizer, filter and route bandwidth routines, cross-banded communications, and the data transmission rate. As described in the RAND root cause analysis, these technologies are at the heart of the differences between the commercial and military variants. Boeing continued to support the high-power HS702HP bus for rapid data transmission rates for the military WGS but switched to the medium-power HS702MP bus for the commercial version. Boeing maintained transponder and channelizer support for military data bands unnecessary to the commercial market—the X-band is used for older military satellites and communications systems, and, although the Ka-band has been explored for commercial purposes, markets have trended toward fiber optic and cell phone data handlers rather than satellite-based communications.

The underlying data for Figure 4.9 are captured in Table 4.6.

As with the DDG-1000 example, understanding the technological differences between somewhat similar platforms—the DDG-1000 versus the DDG-51 and the WGS commercial versus the WGS military—would provide the analyst with a clearer perspective of the nuanced points of risk in these complex systems. In the case of the WGS, this information was critical early in the initial pricing as well as through the WGS design cycle as the commercial market conditions changed.

Table 4.6
Wideband Global Satellite Measures of Merit

Design Category	Measures of Merit	Level of Detail Required	System Complexity
Design life	Years	1	3
Structure	Payload	1	1
Systems	Antennas	1	1
Systems	Launch control	1	2
Orbits	Distance	1	3
Power plant	Solar arrays	1	3
Systems	Communications payload	1	5
Systems	Digital channelizer	2	3
Systems	Filter and route bandwidth routines	2	3
Systems	Cross-banded communications	2	4
Systems	Data transmission rate	2	4
Power plant	Power management	5	1

The 15 percent risk premium accounting artifact that was associated with the Block II units and identified as a considerable cause of the WGS failure would not have been identified by the matrix approach. Although the matrix is a valuable tool for identifying the technical components that contribute risk to the programs, we recommend that the program analyst and decisionmaker view the programs with a variety of tools to gain a more robust understanding of the program risk.

Conclusion

MDAPs are complex systems designed to support specific requirements. As the needs of the battlefield evolve, so will the demand for integrated, better, and faster technologies. The programs described in this report and reviewed in this chapter were designed to integrate cutting-edge components, and in many cases that requirement contributed to the overall program risk. Although each program's life cycle story was slightly different, a common theme is that the additional attention to a selection of critical components early in a program's development could help identify underlying risk before a program fails or a Nunn-McCurdy breach root cause analysis is required.

This chapter describes just one exercise that could be adopted to help identify the most critical components from the long list of program features required of these complex systems. Experience in analyzing the root cause reasons for a Nunn-McCurdy breach suggests that focus on these critical features earlier will help the decisionmaker or reviewing analyst to identify underlying patterns, and this understanding would help identify the initiating hypothesis discussed in this report. Chapter Five furthers this discussion of critical component risk with an analysis of the technical component risk in the Excalibur example. By focusing on the critical components in Excalibur, analysts would have been able to trace scheduling delays, software failures, and simulation and test failures through a two-year and seven-month period of the programs technical component history well before the Nunn-McCurdy breach occurred. This list of critical components was developed as a result of the selective screening thought process described by this chapter.

Although there can be a variety of methods for examining a defense program, more work needs to be done to better characterize programs by their critical components. These important features are often the most difficult to design, integrate, and develop and therefore carry much of the overall program risk.

CHAPTER FIVE

Assessment of Technical Risk in Weapons Programs

Defense acquisition programs are generally large and often require the complex integration of many technologies. This chapter outlines a way to make the complexity of a defense program more transparent for the decisionmaker or reviewing analyst by examining a manageable list of components organized by complexity and the level of detail required to study the component. This chapter documents a process to aid in the early identification of technical risk in the most critical components.

As a result of the RAND root cause analysis of Excalibur, several questions related to the programs technical problems emerged. Using a selective screening of critical components process, outlined in this chapter, the components most necessary to the success of the program were identified. The following is an exploration into the development history of those critical components based on a series of Defense Contract Management Agency (DCMA) parts management program (PMP) and DAES risk assessments. We track those components to see if either DCMA or DAES would have presaged the problems.

The Excalibur DCMA PMP risk assessments were discovered within a series of monthly program reports that were originally produced by the DCMA program integrator and directed to the project manager, combat ammo systems. The monthly reports update cost performance data for the period, current business operations, and technical component-level risk to the system. Two measures of DCMA risk are used throughout the report series: the IMU and the GPS. The GPS and IMU were identified through the selective screening of critical components process as key aspects of the primary goals of the platform.

Section-level measures of risk are based on the DAES risk tri-color rating scale, which is explained in the Department of Defense "Risk Management Guide to DoD Acquisition."[1] Technical component-level risk is captured using the DCMA tri-color

1 Department of Defense, "Risk Management Guide to DoD Acquisitions," Version 6, Washington, D.C., August 2006.

rating scale (green, yellow, and red), which is based on a risk analysis of the probability and consequence of failure to meet the program requirements.[2]

For the purpose of this effort, fluctuations in both the DAES section-level and the DCMA technical component–level risk ratings were used to identify periods of interest in the Excalibur time line. Through this work, we identified a pattern of individual system shocks and serial problems that contributed to larger and longer-term complications for the platform. Future problems for similar programs might be better anticipated by using monthly measures, such as the DCMA technical-level risk assessment, to earlier recognize emerging risks that pose hurdles to meeting the program requirements.

Background

In its two-decade history, Excalibur underwent changes in design, decreases in the quantity planned, and two related program cancellations. Presented in Chapter Two, the RAND root cause analysis of Excalibur determined that the most significant contributors to the Nunn-McCurdy breach, announced during August 2010, were inaccurate estimates of the preliminary unit cost as well as a change to the operational concept of the unit. For a program such as Excalibur that had evolved from an unguided projectile to an entirely different full-GPS and IMU-guided device, these findings are not unexpected.

The root cause analysis also ruled out other difficulties that the program had as nonfactors in the decision to reduce the quantity planned that triggered the initial breach. Many of these were technical problems that were realized during developmental testing, in the production process, and as a result of the relocation of contractor facilities. Although these challenges were not identified as prime factors leading to the Nunn-McCurdy breach, they did delay the program schedule and increase the unit as well as overall costs.[3] The questions that emerged from these technical considerations include: How did these problems with technical aspects evolve from early warnings to larger challenges? And what can be done to identify potential longer-term risk to weapons programs?

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2 Defense Contract Management Agency, *Guide Book: Parts Management Program—Risk Planning*, Washington D.C.

3 The GAO annual report, *Defense Acquisitions: Assessments of Selected Weapons Programs,* has featured the Excalibur program in several editions. The most recent have concluded that the program's history of technical, requirement, and other changes have led to unexpected costs, schedule delays, and reductions in planned procurement. For more information, see GAO, 2010, 2006, 2007, 2008, and 2009, GAO-09-326SP, GAO-08-467SP.

History of Excalibur Unit Costs

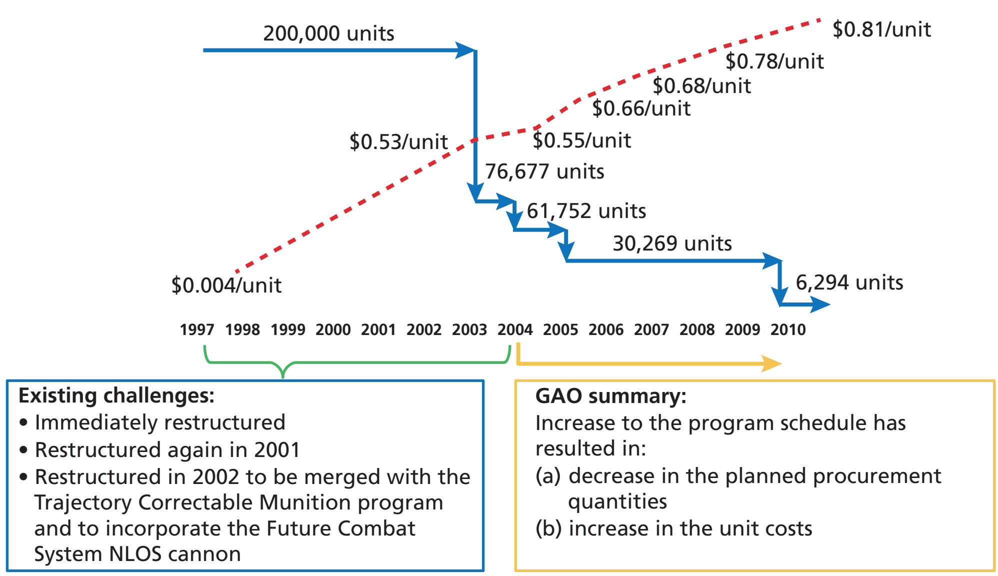
Since 2004, the GAO has tracked the challenges facing major weapon programs in the Department of Defense and each year has included a review of Excalibur. The GAO found existing challenges, before 2004, that led to the Excalibur program's situation. These challenges include several restructures and mergers to incorporate other programs. Depicted in Figure 5.1, the demand for the projectile fell from 200,000 units to only 6,294 between 1997 and 2010, an overall reduction in demand that occurred during four time periods: 2003, 2004, 2005, and 2010. Note that the price per unit continued to increase between 2005 and 2010.

The GAO concluded that the Excalibur program's history of technical, requirements, and other changes led to schedule delays that caused unexpected costs and reductions to planned procurement. To address those issues, the complexity analysis documented in Chapter Four was used to identify the most complex components with the least visibility.

Identifying Areas of Potential Risk

Chapter Four detailed a process for identifying areas of potential program risk based on a RAND-developed methodology to relate measures of merit—the standard mea-

Figure 5.1
GAO History of Excalibur Unit Cost



SOURCES: GAO, 2004–2010.

RAND *MG1171/2-5.1*

sures used by a variety of *Jane's* publications[4] to describe programs—to the complexity and visibility of the components they are used to measure. Relying on RAND experience with the programs, previous work with the source documents and data, and familiarity with the underlying components, we crafted a matrix to explore the relationship between complexity and level of detail or visibility. See Table 5.1 for the full rating scales used to classify the measures of merit.

We coded each measure of merit for both complexity and level-of-detail scales. The results were an alignment of the rating scales to a coordinate plane in a two dimensional 5 × 5 matrix. This allows the assignment of every *Jane's*-based measurement to a coordinate. With this tool, the decisionmaker or analyst can evaluate the frequency of components at various regions of the resultant complexity-detail matrix to better view components of potential risk. In the case of Excalibur, as displayed in Figure 5.2, the most interesting measurements (in the blue shaded square) were the least visible and more complex system components—the systems components for the height of burst, guidance, launch control, and sensors.

Based on the complexity and level of detail review, the measurements identified describe systems components. From experience working with the source documents for Excalibur, the DCMA monthly progress reports were the appropriate information source for more information about these components. Had the complexity-detail analysis revealed that the source of the problem was the projectile's aerodynamics or canards, then the best source of data may have been the engineering and material testing logs or external research and design studies.

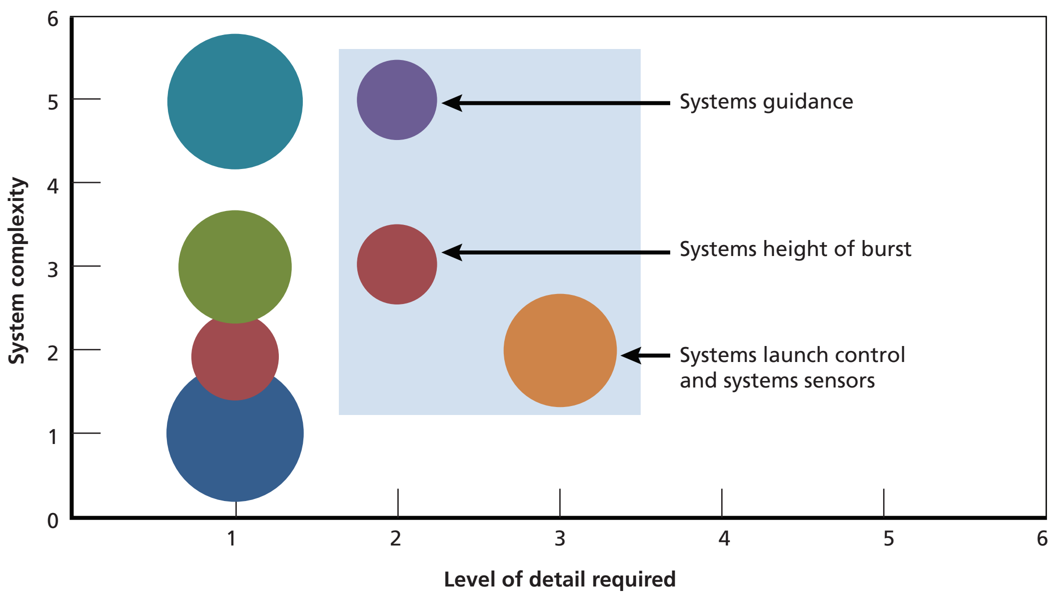
This granular review of the Excalibur program's technical component–level progress was necessary because of questions raised as a result of the root cause analysis reported in Chapter Two. Additionally, we recognized that the Excalibur analysis required different considerations. Analysts found that the most detrimental events in

Table 5.1
Complexity-Detail Matrix Ratings

Value	Level of Detail Required	System Complexity
1	Advertised	Straightforward
2	Available	Integrate existing
3	Accessible	Innovative technique
4	Limited	Complex behavior
5	Buried	Technologically unproven

[4] We initially assembled a list of measures of merit used in *Jane's All the World's Aircraft, Jane's Ammunition Handbook, Jane's Space Systems and Industry,* and *Jane's Fighting Ships* to describe the different programs.

Figure 5.2
Complexity-Detail Matrix for the Excalibur Program



RAND *MG1171/2-5.2*

Excalibur's development history were inaccurate estimates of the preliminary unit cost as well as a change to the operational concept of the unit. However, during the analysis, RAND reviewers mentioned technical concerns but generally with limited specific detail. Late in the analysis, the DCMA monthly progress reports were transmitted to RAND almost as an afterthought.

The newly available greater level of technical detail provided by the monthly progress reports allowed for a more in-depth review of the Excalibur technical concerns. This level of detail is available to the defense acquisitions community but was made available to RAND only for the Excalibur Nunn-McCurdy root cause analysis.

Source Documents Associated with the Critical Components

The DCMA monthly reports that were available for Excalibur covered a two-year and seven-month period of the projectile's 13-year history, but enough data were available to identify patterns. These patterns of problems in the programs technical history contributed to the longer-term risk of not meeting the platform requirements. Early identification of these patterns is necessary to avoid longer-term problems that push programs toward a Nunn-McCurdy breach, which occurs when a system exceeds its initial expected costs. Because of the nature of the problems identified, we determined that our analytical methodology had to devolve to a lower level of detail.

We extracted the desired level of detail information from existing reports. Figure 5.3 is an image from the monthly program reports. Risk rating values from the DCMA reports were compiled to reflect detail status akin to that in Figure 5.6, below.

We found that, over all reporting periods, the overall rating for the Excalibur program never changed from yellow (potential or actual problems) despite a number of underlying technical problems. Figure 5.4 depicts changes to the Excalibur DAES section-level risk ratings. The image captures section-level deviations from the yellow overall rating.

Note that the 1.2 business section remained green (advisory) until March 2010, at which point it changed to yellow (the same as the overall DAES rating for that period). The technical performance rating deviates from the overall DAES rating from December 2008 through March 2009 as depicted by the red (high risk) to yellow branch at the top of the illustration. Schedule performance fluctuates from yellow to green to yellow between March and August 2008 as well as July and November 2009. During the two-year and seven-month period, the overall Excalibur rating never deviated from yellow.

Selective Screening of Critical Components

A complex weapons system such as Excalibur has many moving parts and aspects that can be considered in a risk assessment. The Identification of Potential Risk Areas reduced the number of components to consider to an abbreviated list that was unilaterally system-specific. To get a better understanding of the technical problems during this period, a selective screening of critical components was conducted to further focus the review on a few of the most important aspects.

RAND developed the selective screening specifically to study weapons platforms such as Excalibur. The screening is intended to limit the search for challenges, problems, and failures to just the most critical components. These components are primary aspects of the system and are at the core of the programs function.

The selective screening of critical components begins with two questions about the program: (1) What are the primary goals for the platform? and (2) What technical components will provide the greatest gains toward meeting the requirements for the platform? Answering these questions for Excalibur:

1. What are the primary goals for the platform?

Excalibur was designed to destroy key targets with a minimal of rounds, noncombatant casualties, and other collateral damage. *Precision targeting* is a primary goal for the Excalibur program.

2. What technical components will provide the greatest gains toward meeting the requirements for the platform?

Figure 5.3
Data for the Analysis from DCMA Monthly Reports

DEFENSE CONTRACT MANAGEMENT AGENCY
DCMA MISSILE OPERATIONS
DEFENSE CONTRACT MANAGEMENT AGENCY RAYTHEON - TUCSON
P.O. Box 11337, Building 801, M/S J2
Tucson, Arizona 85734-1337

February 20, 2008

DCMAM-STRRD

MEMORANDUM FOR: Project Manager, Combat Ammo Systems, SFAE-AMO-CAS-EX, LTC Joe Minus

SUBJECT: Excalibur Program Monthly Report for 14 January 2008 – 17 February 2008.

Executive Summary: The overall DAES rating for this reporting period is Yellow (Potential or actual problems). RMS is in the process of delivering AUR's for the FY07 contract. The program continues to experience product risk issues with the IMU, GPS and Data hold Batteries. With the change to the FY07 contract and the final delivery of the FY06 AURs, the requirement for EVM reporting for the Excalibur program will be complete.

1. PROGRAM DATA

1.1 Earned Value: EV Program Analysis (IEAC) FY06 Program: An overall DAES rating of Yellow (Potential or actual problems) has been applied to this section. There was a total of 4 CARs written against Guideline #6, #9, #23 & #27 as a result of the Excalibur

DCMA Excalibur program monthly report reporting period levels (red, yellow, and green) were coded into a database structure.

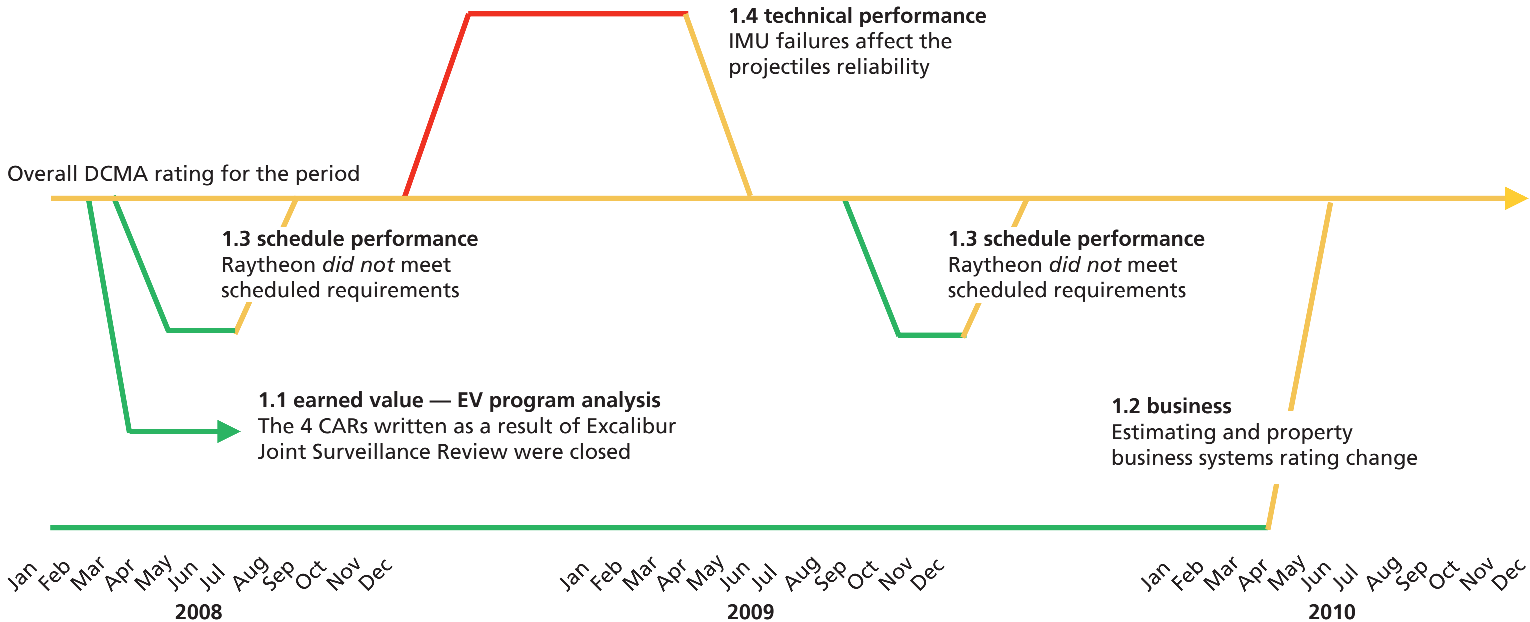
Data were entered by *date*

For the *overall* rating in the executive summary

For the *program data section* rating

NOTE: DCMA color codes are green—no risk, yellow—moderate risk, and red—high risk.
SOURCE: DCMA.
RAND *MG1171/2-5.3*

Figure 5.4
Excalibur DAES Section-Level Changes to the Risk Rating



NOTE: CAR = corrective action request.

RAND *MG1171/2-5.4*

Excalibur uses a GPS that is aided by an IMU in jammed circumstances. Using triangulated guidance, the canards glide or "fly" the projectile to the target. The GPS and IMU enable Excalibur to reach near-vertical angle, achieving impressive precision.

GPS and IMU were identified through the selective screening of critical components as key aspects of the primary goals of the platform. The following section describes an exploration of these components using the DCMA technical-level risk ratings data.

DCMA Technical-Level Risk Ratings

To build a risk history for the GPS and IMU systems, the DCMA risk ratings and the item rank order values for each report were assembled into a research database. Figure 5.5 is a snapshot example of the DCMA risk rating matrix from the monthly progress reports. The matrix contains the core information necessary for the technical-level risk assessment. The DCMA risk ratings in the matrix are based on the consequence and probability of failure to meet the requirements, and the item rank order indicates the top failure concerns—a ranking of #1 is of more concern than a ranking of #6. Taken together, the ratings help to highlight the program components of greatest concern on a month-to-month basis.

The DCMA risk rating matrix data for all of the monthly reports were assembled into a research database to facilitate identification of changes to the valuation of specific components so that analysts could limit a detailed review of the history and log comments in the monthly progress reports to specific components and time periods.

Because of the limited amount of time a decisionmaker or reviewing analyst may have to view and make decisions based on all of the available information, we wanted a way to consider the top-level flags alongside the corresponding lower-level risk ratings. This was a realization based on the findings presented in Figure 5.4; the overall rating never changed from yellow despite an underlying history of lower-level fluctuations in identified risk. Figure 5.6 aligns the DAES (top-level) and DCMA (lower-level) rating scales along a common time line for the IMU to view changes better and consider the differences between the ratings at specific time periods. The DAES ratings are in the leftmost column, and the DCMA data appear in the three right-hand columns. The IMU risk rating was raised to red during the same four-month period, as the section rating deviated from the overall DCMA rating of yellow to red, depicted in Figure 5.6. (Note that the oldest dates are at the top and the newest at the bottom.) Although the DCMA risk ratings for the IMU component are raised only from moderate to high from December 2008 to March 2009, a longer pattern of concern was identified by drilling deeper into the failure rank order of the component (third column from the left). There, it becomes apparent that the IMU had experienced problems as early as February 2008.

The primary goal of the work was to explore why the risk ratings of components have changed over time. The responsive rating time line, depicted on the far right of

Figure 5.5
Image of the DCMA Risk Ratings Matrix

The program data section **1.4 technical performance** was coded

Item rank number

By DCMA risk rating

1.4. <u>Technical Performance</u>: An overall DAES rating of **<u>YELLOW (Potential or actual problems)</u>** has been applied to this section because of engineering concerns as explained below.

No.	ITEM	SUPPLIER	STATUS	DCMA Risk Rating
#1	Inertial Measurement Unit (IMU)	Honeywell	Ongoing failure investigations affecting the projectile's 85% system reliability threshold (TPM). Accepting FY07 IMUs on RDWs that relax the Vibration Rectification Error (VRE) gyro bias requirements because of failed QUAL. Tin whisker mitigation plan established for only half of FY07 production. AG02 Series-1 failed 3 out of 4 rail gun tests while AG02 Series-3 failed 1 out of 4 rail gun tests. AG02 Series-3 being utilized for FY07 production while engineering changes being worked. DCMA predicts that overall system reliability will be jeopardized if future test failures continue to occur.	Moderate
#2	GPS Receiver	L3-IEC	The test flight failures due to loss of satellite acquisition and intermittent issues are affecting projectile's 85% system reliability threshold (TPM). Drivers include crystal oscillator yield failures, conformal coat inconsistencies & test failures. Failure investigations are becoming exhausted with no root cause after year long expenditure. Failure team looking for patterns of the failures from multiple flights including causes of frequency drifts from the oscillator. DCMA predicts that overall system reliability will be jeopardized if future test failures continue to occur.	Moderate
#3	Data Hold Batteries	Eagle Picher	Failure investigation efforts continue. Program requested material transfers from government inventory to cover immediate production needs. Lot #24 has 2 cold rise time failures that need waivers to allow shipment for lot #24 and is at risk for shipment with the program if this lot is not deemed acceptable for waiver. RMS/EPT is currently testing different scenarios to resolve the lots in question. The cold LAT environment is still an on going risk. DCMA predicts delivery schedule slips from shortage of parts if lot acceptance tests (LAT) continue to fail.	Moderate
#4	Propulsion Base	Bofors	It is evident that the failure mode is a combination of events: unique test conditions, assembly/rework process, and a design margin. Evidence demonstrates that there is no credible risk to the muzzle brake or the gun crew per SSRA. Redesign efforts continue at Bofors to lower the probability of future base failures. These efforts include increasing the strength of the M40/48 threads, lower the height of the flange and increase the number of pins in the slipping driving band for increased sectional breakup within the muzzle brake. There is a risk on redesign efforts meaning that fixing a problem might create entirely new problems.	Low

Top Failure & Risk Drivers

RAND *MG1171/2-5.5*

Figure 5.6
IMU DCMA Technical Component-Level Risk Rating History

Section rating | **Component detail rating** | **Responsive time line**

Date	1.4 Technical Performance	DCMA Risk Rating	Failure Rank Order	Date
2/20/2008	Yellow	Moderate	1	2/20/2008
3/20/2008	Yellow	Moderate	1	3/20/2008
4/15/2008	Yellow	Moderate	1	4/15/2008
5/20/2008	Yellow	Moderate	1	5/20/2008
6/13/2008	Yellow	Moderate	4	**6/13/2008**
7/15/2008	Yellow	Moderate	3	**7/15/2008**
8/15/2008	Yellow	Moderate	2	**8/15/2008**
9/17/2008	Yellow	Moderate	2	9/17/2008
10/8/2008	Yellow	Moderate	2	10/8/2008
11/18/2008	Yellow	Moderate	2	11/18/2008
12/11/2008	Red	High	1	**12/11/2008**
1/21/2009	Red	Moderate	2	**1/21/2009**
2/12/2009	Red	High	1	**2/12/2009**
3/13/2009	Red	High	1	3/13/2009
4/15/2009	Yellow	Moderate	1	4/15/2009
5/15/2009	Yellow	Moderate	4	**5/15/2009**
6/17/2009	Yellow	Moderate	4	6/17/2009
7/17/2009	Yellow	Moderate	4	7/17/2009
8/12/2009	Yellow	Moderate	4	8/12/2009
9/14/2009	Yellow	Moderate	4	9/14/2009
10/19/2009	Yellow	Low	6	**10/19/2009**
11/13/2009	Yellow	NONE	NONE	**11/13/2009**
12/15/2009	Yellow	Moderate	2	**12/15/2009**
1/15/2010	Yellow	Moderate	2	1/15/2010
2/18/2010	Yellow	Moderate	2	2/18/2010
3/18/2010	Yellow	Moderate	1	**3/18/2010**
4/21/2010	Yellow	Moderate	1	4/21/2010
5/18/2010	Yellow	Moderate	1	5/18/2010
6/18/2010	Yellow	Moderate	1	6/18/2010
7/16/2010	Yellow	Moderate	1	7/16/2010
8/17/2010	Yellow	Moderate	1	8/17/2010
9/20/2010	Yellow	Moderate	1	9/20/2010

Technical performance problems during a four-month window from the end of 2008 to March 2009

IMU DCMA risk rating **fluctuates between high and moderate** during this period

IMU failure rank order changes during the cycle suggest that the IMU challenges may have started earlier

Challenges associated with the IMU may be on the horizon

RAND *MG1171/2-5.6*

Figure 5.6, summarizes the major DAES and DCMA changes to the IMU risk ratings. On the responsive time line, white reflects periods in which the rating scale has not changed and therefore nothing has occurred to improve or hinder the programs progress toward meeting the requirements. Periods colored red represent the highest risk to the program and green periods the least.

By studying the comments and other data discussed in the monthly DCMA program reports, we were able to gain a better understanding of the significance of the risk rating change during a specified time period. As a result, the key dates in the IMU responsive time line indicate that problems with the design, supplier, and software were present well before the DAES section-level rating changed from yellow to red. Specifically, we found failure investigations related to the IMU between February and June 2008 and quality/design issues with the manufacturer from the beginning of the time period in February 2008 to February 2009. These challenges represent serial patterns of increasing risk.

After reviewing the top- and lower-level ratings as aligned to the common calendar in Figure 5.6, the responsive rating time line shown in Figure 5.7 was constructed so that analysts could connect key dates to the program office descriptions also found in the DCMA monthly progress reports. This connection allowed for a more qualitative analysis of specific changes to the ratings, contextualizing the root cause challenges that persisted from one period to the next. The key dates used to construct the responsive rating time line, shown in Figure 5.7, reveal that the shock related to IMU risk (December 2008 to March 2009) occurred after a pattern of serial risk. Failure investigations of the IMU were ongoing from February to June 2008 and quality as well as design concerns through February 2009. The shocks to the IMU progress are all related to failures or cracks in components that occurred during testing. In Figure 5.6, shocks reflect increased risk levels during a one- to two-month period (red) and serial patterns reflect risk with a longer duration (orange). Periods of interest are marked with a blue border.

Through the selective screening of critical components, the GPS was also identified as a system of interest. Similar to the IMU, the technical component–level DCMA risk rating matrix data for the GPS were captured and analyzed for fluctuations over time using the same methodology as for the IMU analysis (See Figure 5.8, which depicts the GPS receiver DAES and DCMA risk rating data.)

Figure 5.8 depicts an underlying pattern of DCMA component risk related to the GPS receiver. The failure rank order data indicate that the GPS receiver was a concern well in advance of the February shock. The DCMA component-level and the failure rank order rating changes were used to construct a responsive time line documenting the history of risk facing the component.

Similar to the IMU, the responsive time line for the GPS was used to identify time periods to review more thoroughly to identify the cause of the ratings fluctuation.

Figure 5.7
Patterns of Risk Shown in the IMU Responsive Time Line

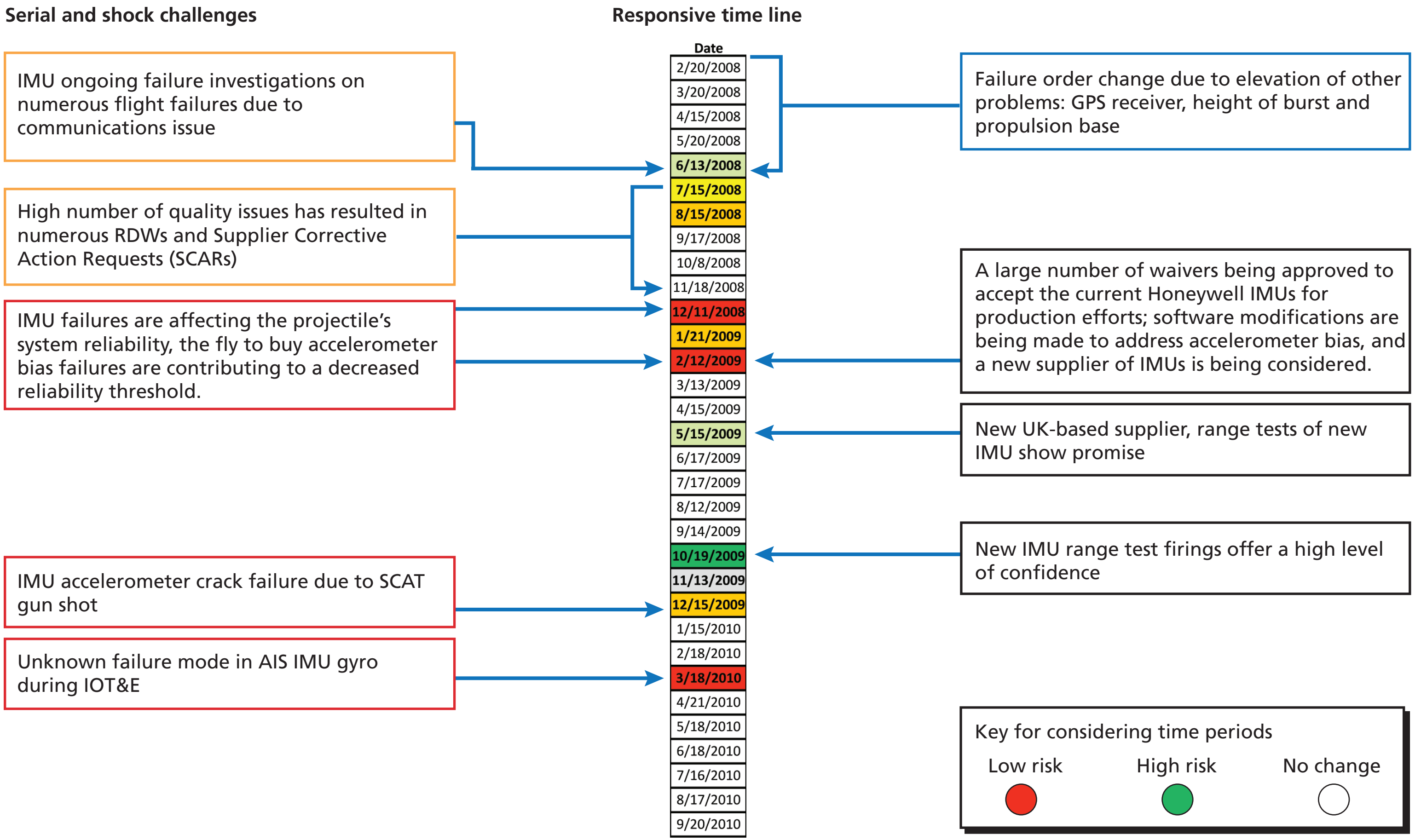


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Figure 5.8
GPS Receiver DCMA Risk Ratings Data

Section rating: Date	Section rating: 1.4 technical performance	Component detail rating: DCMA risk rating	Component detail rating: Failure rank order	Responsive time line: Date
2/20/2008	Yellow	Moderate	2	2/20/2008
3/20/2008	Yellow	Moderate	2	3/20/2008
4/15/2008	Yellow	Moderate	2	4/15/2008
5/20/2008	Yellow	Moderate	2	5/20/2008
6/13/2008	Yellow	Moderate	1	6/13/2008
7/15/2008	Yellow	Moderate	1	7/15/2008
8/15/2008	Yellow	Moderate	1	8/15/2008
9/17/2008	Yellow	Moderate	1	9/17/2008
10/8/2008	Yellow	Moderate	1	10/8/2008
11/18/2008	Yellow	Moderate	1	11/18/2008
12/11/2008	Red	Moderate	2	12/11/2008
1/21/2009	Red	Moderate	1	1/21/2009
2/12/2009	Red	Moderate	4	2/12/2009
3/13/2009	Red	Moderate	4	3/13/2009
4/15/2009	Yellow	Moderate	3	4/15/2009
5/15/2009	Yellow	Moderate	1	5/15/2009
6/17/2009	Yellow	Moderate	1	6/17/2009
7/17/2009	Yellow	Moderate	1	7/17/2009
8/12/2009	Yellow	Moderate	1	8/12/2009
9/14/2009	Yellow	Moderate	1	9/14/2009
10/19/2009	Yellow	Moderate	1	10/19/2009
11/13/2009	Yellow	Moderate	2	11/13/2009
12/15/2009	Yellow	Moderate	4	12/15/2009
1/15/2010	Yellow	Moderate	4	1/15/2010
2/18/2010	Yellow	High	1	2/18/2010
3/18/2010	Yellow	Moderate	3	3/18/2010
4/21/2010	Yellow	Moderate	3	4/21/2010
5/18/2010	Yellow	Moderate	3	5/18/2010
6/18/2010	Yellow	Moderate	3	6/18/2010
7/16/2010	Yellow	Moderate	3	7/16/2010
8/17/2010	Yellow	Moderate	3	8/17/2010
9/20/2010	Yellow	Moderate	3	9/20/2010

Technical performance section problems do not align with GPS receiver ratings

GPS receiver DCMA risk rating does not affect the section rating

Despite the DMA risk ratings, the GPS receiver is ranked consistently high on the list of top failures

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Figure 5.9 depicts the GPS responsive time line with associated notes about performance, failures, and technical challenges.

In February 2010, well before the failed simulation and testing, the GPS experienced a series of communication and software failures that were present in the data as early as February 2008. Also shown on the time line, problems with the GPS receiver satellite vehicle dropout (a software-based problem) resulted in numerous flight failures in June 2008. These persistent challenges resulted in lost time that delayed the program schedule.

As the risk ratings data are list-driven, the rank order of risks lead to a change in the ratings. As another component rises or falls in failure rank order importance, that change affects the ratings of all others. Figure 5.9 captures an example of this type of change. Because of an elevated risk of failure in February 2009 that was related to the IMU, height of burst, and data hold batteries, the GPS rating changed from orange to green or from more to less risk. This example of change resulting from the order of other risks does not dilute overall concern for the GPS receiver.

Discussion

Both the IMU and GPS receiver are technical components critical to the overall function of Excalibur and have been the source of considerable risk over a long period of the programs history. Problems with the IMU quality, the accelerometer, and IMU gyro, as well as a change in suppliers, contributed to this history. In the GPS receiver system, software and integration challenges contributed to simulation and testing failures. Over the two-year and seven-month period, these persistent problems led to delays in the program. If the DAES section-level and DCMA technical component–level risk ratings are not followed, the persistent challenges facing these central components may remain unnoticed.

The experience in tracking the history of technical problems faced by the Excalibur program through the DCMA risk assessments informed the methodology depicted in Figure 5.10 to help identify potential longer-term risk to platforms. Using the appropriate time series data source—in the case of the Excalibur IMU and GPS receiver, this was the DCMA monthly program reports—fluctuations in the risk ratings are captured on the responsive time line. These points of change from higher to lower or lower to higher risk are further researched through the comments, figures, and other data presented in the monthly reports. Conclusions related to each change in the ratings are summarized along with the responsive time line to provide the analyst with a sense of the gravity associated with persistent problems and shock failures.

The persistent problems should be tackled by the analyst and program managers first. These are the components and systems to inquire about regularly and to fully understand before they contribute to a shock failure event such as the GPS-related simulation failure or failures with the accelerometer or IMU gyro. The exploration of

Figure 5.9
GPS Receiver Pattern of Failures

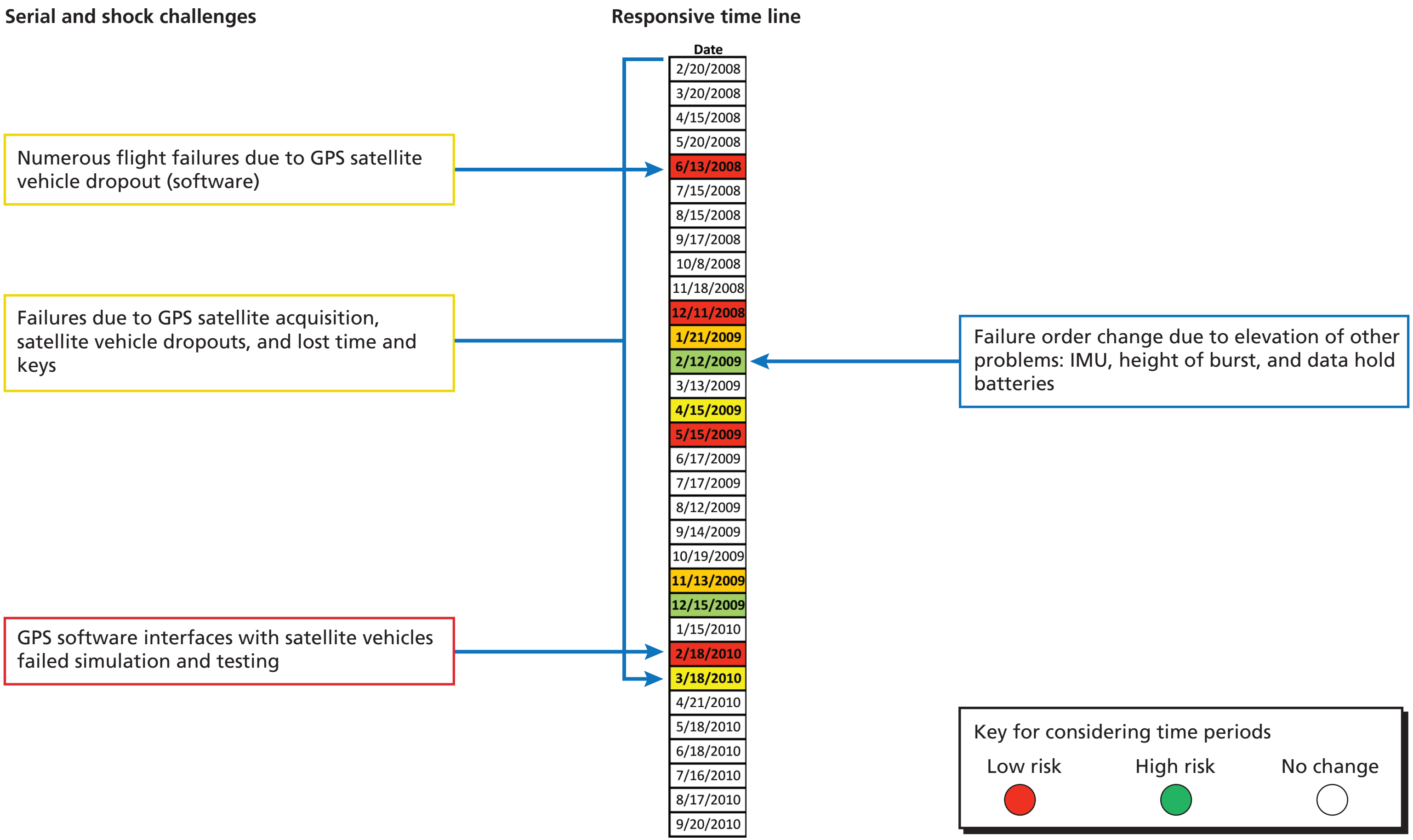

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Figure 5.10
Proposed Change Model Based on the Responsive Time Line

Use existing data to explain changes over time

Created the responsive rating time line

1. Identify a change in level of DCMA risk detail (section-level, component DCMA risk rating, and failure rank number)

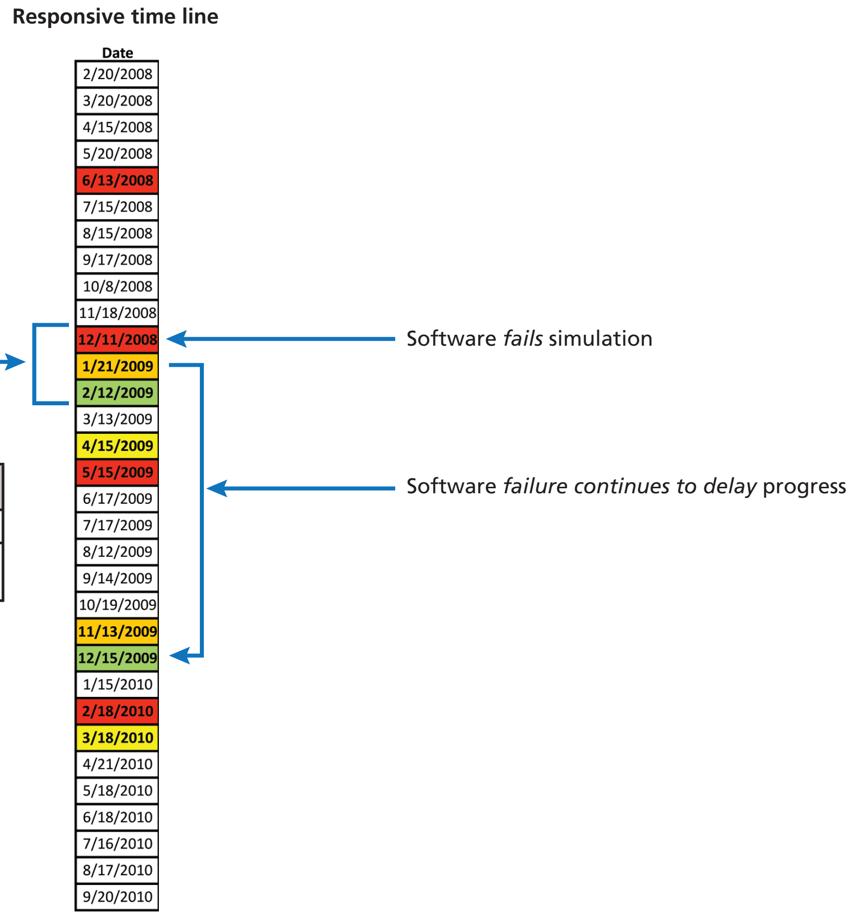
2. Explain the change by summarizing the comment text or component level status reports

3. Determine the nature of the change—is the change the effect of a shock or a serial problem

Challenge type	Description	Date
Shock	Software fails simulations	12/11/2008
Serial	Software failure continues to delay progress	12/11/2008–12/15/2009

Tackle the *serial* problems first

Use the responsive rating time line and nature of the changes to identify key questions and resolutions before they extend the schedule further and increase the program costs



RAND *MG1171/2-5.10*

technical risks to the Excalibur program revealed a pattern of shocks and serial problems that contributed to larger and longer-term complications for the platform.

Conclusion

The RAND-led root cause analysis of Excalibur identified a few specific points in the programs unit cost history that contributed to the breach. The analysis also revealed several concerns related to the potential technical risk in the program. This chapter has explored the technical risk further by examining a series of monthly progress reports. Analysis of the DAES and DCMA risk ratings of technical components within those reports suggests that problems related to the GPS receiver and IMU were well documented in the more granular technical component–level risk data well before red flags were raised at the overall technical level. Furthermore, the investigation also revealed that fluctuations in the granular and even the section-level data occurred without ever raising red flags at the overall Excalibur program level. The persistence of more granular technical problems led to larger shock events, which contributed to schedule delays, simulation and testing failures, and ultimately to the Excalibur unit cost breach.

As MDAPs become increasingly complex and operationally more closely interrelated, new techniques must be developed to enrich the decisionmaker's and the reviewing analyst's understanding and grasp of critical points of potential program risk. This chapter introduced one approach to identify technical component–level risk. The Excalibur example described here is not a unique case, as the DAES and DCMA risk rating data points studied were taken from the reports generated regularly by the defense acquisition community. Other similar sources of data covering a variety of other MDAP performance measures exist within regularly generated defense acquisition reports. The Nunn-McCurdy investigations provide a prime opportunity for these reports and their rating scales to be reviewed and to be better used. Reports that are common to the acquisitions and defense contracting community could be used to create new analytical methods for evaluating an MDAP's progress through all phases of the program's life cycle.

CHAPTER SIX

Concluding Observations

This report has presented the results of root cause analyses of two programs. It has also laid out and illustrated a methodology that program managers could apply to focus attention on the elements of an acquisition program most likely to lead to a Nunn-McCurdy breach. To date, RAND has completed root cause analyses of six programs. It is important that the perspectives gathered through these analyses be shared and understood as we come into the next full season of Nunn-McCurdy reporting. We therefore offer our observations on the conduct of RCA.

Root Cause Analyses of Nunn-McCurdy Breaches

Excalibur

RAND's root cause analysis identified one primary driver and four contributing factors to Excalibur's Nunn-McCurdy cost breach. The primary driver of cost increase was the change in procurement quantities, specifically, a 79 percent reduction in Excalibur rounds ordered. The root causes of this quantity reduction were changes in requirements combined with affordability considerations. The manner in which artillery was being used and the precision of the Excalibur round meant that fewer would be needed.

Four other factors contributed to some program cost growth before the decision was made to reduce procurement quantity:

- inaccurate estimates
- concept and technological change
- minor technical issues
- urgent operational need.

Inaccurate cost estimates contributed to some cost growth. Both the original May 1997 cost estimates and the initial SAR estimates were too low to reflect the technological improvement represented by Excalibur, making an eventual cost overrun more likely. Additional drivers of the cost growth before the breach include a concept and technological change that occurred between the original solicitation and the contract

award in January 1998, as well as some *minor technical issues* between 2002 and 2010. Finally, Excalibur unit cost growth was driven by the validated and urgent operational need during OEF/OIF, which caused production to be accelerated and the production of more Increment Ia rounds than initially planned.

Excalibur was unaffected by other potential root causes. For example, Excalibur lived up to its performance expectations, was not affected by poor government or contractor performance, and had sufficient and fairly stable sources of funding.

Navy Enterprise Resource Planning

Although the Navy ERP program technically breached the Nunn-McCurdy cost growth limits and was implemented behind schedule, the program can still be considered a qualified success. Most cost growth and schedule delays occurred in 2004 and 2005. Since the 2006 re-baseline, costs have stabilized and production delays have been limited.

The root cause of the 2004 cost overrun stemmed from two sources. One was a somewhat optimistic baseline for cost and schedule. The second and greater problem was the unexpected change in business practices caused by the Navy's decision, after the BRAC process, to move maintenance from an intermediate-level construct to a regional one. The latter led to the major schedule slippage in 2005 and forced the ERP program to jettison its extension to maintenance activities.

The ERP program was re-baselined in 2006 at $400 million higher. The increase arose from a redesign of the system, the change in business practices, and an improvement in estimates. Since 2006, ERP costs have stabilized and the program has been successfully implemented at three SYSCOMs. Some additional schedule slippage has occurred primarily because of timing issues rather than program delays or failures.

The Navy ERP can be considered a qualified success. Although initial cost growth and schedule slippage were significant, they were not extreme, and the ERP program was never in real danger. Several factors may have contributed to relative program success, including the use of pilot projects, cost-plus contacting, the decision to minimize the customization of the SAP solution, interactive governance and high leadership interest, and a willingness to rely on the managerial and technical expertise of civilian cadres.

Program Complexity and Risk

Our analysis of the six programs that had Nunn-McCurdy breaches indicates that it is possible to identify when a program may be at risk of a breach far sooner than has been the case in the past. Not all aspects of a program have the same potential to lead to a breach. The challenge for program managers is to focus on the elements of the program most likely to lead to a breach. Two attributes—level of complexity and detail—can

help identify those elements. The components of a program that are especially complex and require a high level of detail are the ones that require the most attention.

By identifying those elements early and focusing on them, a program manager can uncover early indications of when these elements may be leading to higher program risk. MDAPs have voluminous documentation. Using complexity and level of detail to identify program elements that lie along the critical path to success, program managers need to delve into the documentation of elements for signs of risk. This means going well below the summary-level documentation, because in the aggregation of ratings to the system level, important details can be missed.

Observations on the Conduct of an RCA

Many sources of data must be consulted to allow the RCA team to compile, understand, and interpret key events in a program's history, from military requirements and financial, technical, contractual, schedule, and acquisition environment perspectives. Key sources of data to attain this knowledge include ADMs, acquisition strategies, Cost Analyses Requirements Description, DAES, DCMA reports, information gained in interviews, formal letters of notification to Congress of Nunn-McCurdy breaches, Nunn-McCurdy Overarching Integrated Process Team cost and management briefings, other official program briefings, PDRs, SARs, and OUSD (AT&L) program memoranda. Numerous secondary sources of data also must be consulted to verify data and solidify insights offered by primary data sources. Interviews with program and industry officials are also valuable sources of information and provide insights that are difficult to gain from only documentation. The precise combination of documents and interviews appropriate for each RCA evolves during the course of conducting the analysis. Since repeat consultations with various sources are part of the RCA process, the data sources should be recorded in bibliographical form for inclusion in the formal report and in searchable form for future consultation.

Although each program is unique and thus each RCA is unique, a set of core activities is instrumental to a successful root cause analysis. These activities define a generic root cause methodology whose key components include the following:

- Develop a hypothesis.
- Set up long-lead-time activities.
- Document the unit cost threshold breach.
- Construct a time line of cost growth relevant events in the program history.
- Verify the cost data and quantify cost growth.
- Create and analyze the program cost profiles pinpointing occurrences cost growth.
- Match the time line events with the changes in the cost profiles and derive root causes of cost growth.

- Reconcile remaining issues.
- Attribute unit cost growth to root causes.

Execution of the above activities should result in enough useful material for an RCA team to create the primary outputs supporting a root cause analysis: a summary narrative that includes clearly stated root causes of cost growth supported by a formal documentation of the cost threshold breach, a summary time line of program events leading to the Nunn-McCurdy breach, funding profiles, a completed PARCA office–generated root cause matrix, and a breakdown of the amount of cost growth attributable to each root cause; an informal briefing incorporated into the final report; and a full root cause final report.

RAND has conducted six RCAs for the PARCA office. These efforts have generally involved three to four personnel working rapidly for an average of 35 days. As described above, vital to the success of these efforts was timely access to a wide variety of program documentation and people involved in the program. A companion publication associated with this project arrays the sources in a different manner to fully explore both the nature of the data available for use and the source of various data in addition to the data found from more customary approaches.[1] This list of sources is an important one to appreciate fully because, although some data can be gathered from certain sources in anticipation of a breach occurring, some significant quantity of data can be gathered only after the secretary of the cognizant military department notifies Congress of the Nunn-McCurdy breach. The discussion and graphs contained in the companion report fully support the ability to make distinctions as to the categories and sources of data as they become available for users. Analysts preparing to examine these potential and notified breaches need to be aware of the distinctions to be able to set up the long-lead-time activities addressed earlier in our generic methodology.

It is important to remember that each program is unique and the sequence of events that lead to a program's unit cost threshold breach will be unique as well. Although this report describes the basic data sources that should be consulted and a generic methodology for successfully conducting a root cause analysis, further RCAs may require only part of the methodology and only some data sources, whereas others may require all that is described plus much more. Hence, to conduct an RCA within the legally allotted time frame, analysts will need to be diligent in pursuing sources of information that can lend insight to the analysis.

The last two analyses conducted by RAND exemplify this need for resourcefulness and adaptation. For Excalibur, the data available and provided initially were not useful in answering certain questions dealing with program status. It was only after the RCA was largely complete that certain data were captured and examined more fully. These data, developed by DoD on an ongoing basis, if viewed correctly, would enable a

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[1] See Blickstein et al., forthcoming.

continuing risk analysis of programs by acquisition leaders. The data supporting a risk analysis were not gathered easily or even for all programs examined by RAND, and this continues the experience addressed in Blickstein et al., 2011.

Similar to the cost-based approach to the Excalibur RCA, the risk analysis of technical components revealed that challenges early in the program's history increased the risk of not meeting requirements. The approach described in Chapter Five used a responsive rating time line to track the performance of several components critical to Excalibur and found that as early as February 2008, the GPS receiver and IMU were emerging concerns. Although problems with the IMU accelerometer triggered a higher-level risk rating at the end of 2008, problems related to the GPS remained obscured in component details until simulation and testing failures during February 2010. The approach outlined in this chapter is provided to help identify a methodology to highlight questionable performance before a failure. Although there needs to be a standard for data supporting MDAP oversight, it may well be that, given the nature or source of the programs considered, some special approaches such as that presented here may be useful.

Critical to assembling the responsive rating time line used in Chapter Five is the selective screening of critical components exercise described in Chapter Four. Completion of the RCAs reported in this document led to a clearer understanding of the need to focus the review of MDAP material early in any analysis. This realization has become a cornerstone to the methodology presented in Blickstein et al., forthcoming, and Chapter Four proposes that this type of exercise might also be useful for decisionmakers before a program triggers a Nunn-McCurdy breach. The authors felt that emphasis on the complex and least visible components of a program would be most useful, though clearly other frameworks can be devised. The exercise described in Chapter Four identifies the components of most interest to the decisionmaker, and the methodology outlined in Chapter Five describes the depth of analysis necessary to reveal underlying risks. The strategies discussed will help a decisionmaker design an inquiry strategy for uprooting risk from complex programs.

Our examination of our last two programs also provided insight that led to the designation of another approach in examining program execution for consideration. First with Excalibur and then again with Navy ERP, understanding the fundamental characteristics of the requirements relationships of programs entering into an MDAP or other senior review and oversight process appears to be essential to both fuller oversight as well as more complete analysis. With Excalibur, one observation is that one size does not fit all. Methodologies that look at all programs the same way fail to look at programs in necessary ways. In this report, Excalibur is explored at the macro level through the root cause analysis presented in Chapter Two and at the granular level in Chapter Five. This was necessary, partly because of Excalibur's development history in relation to other systems and partly as a defense system unlike other programs assigned to RAND to date for review.

The programmatic relationship between the Army's sweeping modernization program Future Combat System and Excalibur was known. That relationship had embedded into it certain requirements and technical interrelationships that may well have been central to the ultimate success of Excalibur. With the demise of Future Combat System, a fuller examination and understanding of the implication for Excalibur might have led to a better understanding of quantity issues. This greater understanding may have led to earlier decisions and a re-base to the assumptions tied to the modernization architecture in addition to the individual programs realities. To the extent that DoD has similar situations with various overarching modernization architectures, it may well serve a useful purpose to engage in architecture-oriented reviews. DoD is currently suggesting that quantity-related breaches be waived from Nunn-McCurdy provisions. Care should be taken in pursuing this initiative so that more central issues than mere quantity reduction are not masked.

In the case of Navy ERP, we were able to see in the process of the RAND review that the central characteristic of the program was the re-engineering of business processes, many of them dating to World War II. The recognition of this characteristic is central to oversight and analysis of such a program. Its implications appear to be insufficiently (if at all) understood by higher authority. The lack of understanding reinforces our view of the need for clarity in understanding the often complex relationships and characteristics that modern programs entail. Understanding the relationship of processes being re-engineered, by both in-house and government and contractor personnel in supporting activities, to the software being procured from outside vendors is critical to understanding the nature of cost estimates and program performance. As a result of the understanding gained across all six of the programs reviewed and as particularly illuminated by the difficulty in analyzing Excalibur and Navy ERP using traditional program review approaches, RAND developed an in-house template for understanding the requirements relations preposition. That template can be found in Chapter Five. It is provided to help the PARCA office explore new and possibly more useful approaches going forward.

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